U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-297 576

# Regional Air Pollution Study, Quality Assurance Audits

Rockwell International, Creve Coeur, MO Air Monitoring Center

Prepared for

Environmental Sciences Research Lab, Research Triangle Park, NC

May 79

United States
Environmental Protection
Agency

Environmental Sciences Research
Laboratory
Research Triangle Park NC 27711

EPA-600/4-79-031
May 1979

Research and Development

EPA

# Regional Air Pollution Study

PB 297576

JUN 18 1979

# Quality Assurance Audits

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

## RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL MONITORING series. This series describes research conducted to develop new or improved methods and instrumentation for the identification and quantification of environmental pollutants at the lowest conceivably significant concentrations. It also includes studies to determine the ambient concentrations of pollutants in the environment and/or the variance of pollutants as a function of time or meteorological factors.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

TECHNICAL REPORT DATA
*(Please read Instructions on the reverse before completing)*

| 1. REPORT NO. | 2. | 3. RECIPIENT'S ACCESSION NO. |
|---|---|---|
| EPA-600/4-79-031 | | PB297576 |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| REGIONAL AIR POLLUTION STUDY<br>Quality Assurance Audits | May 1979<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
| O. Klein and F. Littman | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Rockwell International<br>Air Monitoring Center<br>11640 Administration Drive<br>Creve Coeur, MO 63141 | 10. PROGRAM ELEMENT NO.<br>1AA603 AA-126 (FY-79)<br>11. CONTRACT/GRANT NO.<br>68-02-2093<br>Task Order 106 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Environmental Sciences Research Laboratory - RTP, NC<br>Office of Research and Development<br>U.S. Environmental Protection Agency<br>Research Triangle Park, NC 27711 | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final<br>14. SPONSORING AGENCY CODE<br>EPA/600/09 |
| 15. SUPPLEMENTARY NOTES | |


16. ABSTRACT

RAPS Quality Assurance audits were conducted under this Task Order in continuation of the audit program previously conducted under Task Order No. 58. Quantitative field audits were conducted of the Regional Air Monitoring System (RAMS) Air Monitoring Stations, Local Air Monitoring Stations (State of Illinois, St. Louis City, and St. Louis County), RAPS helicopters and various measurement systems employed in the RAPS intensive studies. Audit results are reported for systems measuring NO, $NO_x$, $O_3$, $SO_2$, total sulfur, total hydrocarbons, $CH_4$ and CO.

An investigation was conducted on the effect of Teflon particulate filters on NO, $NO_2$, $O_3$, and $SO_2$ concentrations in sampled air. Measured sample losses are reported for synthetic pollutant - air mixtures sampled through new and used filters under both dry and humid conditions. The investigation also revealed effects of humidity on the response of analyzers to the various pollutants.

The accuracy of $SO_2$ calibration mixtures prepared with the commercial dynamic calibration system employed in the audits was investigated. As a result of this investigation and experience gained during the audits, the calibration system was modified to improve performance under field conditions.


17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| * Air Pollution<br>* Quality Assurance<br>* Auditing | St. Louis, MO<br>Regional Air Pollution Study | 13B<br>14D<br>05A |

| 18. DISTRIBUTION STATEMENT | 19. SECURITY CLASS *(This Report)* | 21. NO. OF PAGES |
|---|---|---|
| RELEASE TO PUBLIC | UNCLASSIFIED | 135 |
| | 20. SECURITY CLASS *(This page)* UNCLASSIFIED | 22. PRICE A07- A01 |

EPA Form 2220-1 (9-73)

EPA-600/4-79-031
May 1979

# REGIONAL AIR POLLUTION STUDY

## Quality Assurance Audits

by

O. Klein
F. Littman
Air Monitoring Center
Rockwell International
11640 Administration Drive
Creve Coeur, MO 63141

Contract No. 68-02-2093
Task Order 106

Project Officer

Stanley Kopczynski
Organic Pollutant Analysis Branch
Environmental Sciences Research Laboratory
Research Triangle Park, NC 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

## DISCLAIMER

This report has been reviewed by the Environmental Sciences Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendations for use.

## ABSTRACT

RAPS Quality Assurance audits were conducted under this Task Order in continuation of the audit program previously conducted under Task Order No. 58. Quantitative field audits were conducted of the Regional Air Monitoring System (RAMS) Air Monitoring Stations, Local Air Monitoring Stations (State of Illinois, St. Louis City, and St. Louis County), RAPS helicopters and various measurement systems employed in the RAPS intensive studies. Audit results are reported for systems measuring NO, $NO_x$, $O_3$, $SO_2$, total sulfur, total hydrocarbons, $CH_4$ and CO.

An investigation was conducted on the effect of Teflon particulate filters on NO, $NO_2$, $O_3$, and $SO_2$ concentrations in sampled air. Measured sample losses are reported for synthetic pollutant - air mixtures sampled through new and used filters under both dry and humid conditions. The investigation also revealed effects of humidity on the response of analyzers to the various pollutants.

The accuracy of $SO_2$ calibration mixtures prepared with the commercial dynamic calibration system employed in the audits was investigated. As a result of this investigation and experence gained during the audits the calibration system was modified to improve performance under field conditions. The air scrubber and dilution air flow measurements and control were modified to eliminate the undesirable effects of uncontrolled ambient temperature and humidity. A new permeation tube holder was designed and constructed to eliminate a recurrent air leakage problem.

CONTENTS


| | |
|---|---|
| Abstract | iii |
| Figures | vi |
| Tables | vii |
| 1.0 Introduction | 1 |
| 2.0 Summary | 2 |
| 3.0 Quality Assurance Audits | 4 |
| 3.1 Instrumentation | 4 |
| 3.2 Van Preparation | 5 |
| 3.3 Van Operation | 7 |
| 3.4 Bendix Portable Calibrator | 7 |
| 3.5 Audit Standards | 24 |
| 3.6 Results and Discussion | 26 |
| 3.6.1 Data Analysis Methods | 26 |
| 3.6.2 Audit Results | 35 |
| 4.0 Filter Study | 38 |
| 4.1 Experimental | 38 |
| 4.2 Results and Discussion | 40 |
| 5.0 Calibrator Operating Variables; an $SO_2$ Study | 57 |
| 5.1 Equipment | 57 |
| 5.2 Permeation Tube Variables | 60 |
| 5.3 Temperature Excursions | 62 |
| 5.4 Results and Discussion | 62 |
| Appendices | |
| A. Audit Procedures for RAPS Instrument Systems | 71 |
| B. Modified Bendix Model 8861 Portable Calibration System | 99 |




Preceding page blank

FIGURES


| Number | | Page |
|---|---|---|
| 1 | Winnebago Wiring | 6 |
| 2 | Installation of Instruments in Winnebago | 8 |
| 3 | Flow Calibration Equipment | 10 |
| 4 | Orifice No. 1 Calibration Curve | 15 |
| 5 | Orifices 1 and 2 Calibration Curve | 16 |
| 6 | Orifices 1 and 3 Calibration Curve | 17 |
| 7 | Orifices 1 and 4 Calibration Curve | 18 |
| 8 | Orifices 1 and 5 Calibration Curve | 19 |
| 9 | Orifices 1, 2 and 3 Calibration Curve | 20 |
| 10 | Orifices 1, 2, 3 and 4 Calibration Curve | 21 |
| 11 | Orifices 1, 2, 3, 4 and 5 Calibration Curve | 22 |
| 12 | NO Capillary Calibration Curve | 23 |
| 13 | Typical Audit Data Record | 27 |
| 14 | Schematic Layout for Filter Study | 39 |
| 15 | NO Pollutant | 45 |
| 16 | $NO_2$ + $O_3$ Pollutant | 47 |
| 17 | Ozone Pollutant | 49 |
| 18 | $SO_2$ Pollutant (Tracor) | 51 |
| 19 | $SO_2$ + $O_3$ Pollutant, $SO_2$ | 53 |
| 20 | $SO_2$ + $O_3$ Pollutant, $O_3$ | 54 |
| 21 | $SO_2$ Pollutant (Meloy) | 56 |
| 22 | Initial Equipment Configuration for $SO_2$ Study | 58 |
| 23 | Final Equipment Configuration for $SO_2$ Study | 59 |
| 24 | Meloy $SO_2$ Analyzer Calibration | 61 |
| 25 | Typical Strip Chart Trace, $SO_2$ Study | 66 |

TABLES


| Number | | Page |
|---|---|---|
| 1 | Bendix 8861 Orifice Calibration Data | 11 |
| 2 | Data Summary - Rams Stations | 29 |
| 3 | RAPS Helicopters | 31 |
| 4 | St. Louis City and County Stations | 32 |
| 5 | Illinois Stations | 33 |
| 6 | Miscellaneous Audits | 34 |
| 7 | Summary of Results for Particulate Filter Study | 41 |
| 8 | Data Summary, NO Pollutant Monitor Labs Instrument | 44 |
| 9 | Data Summary $NO_2$ + Ozone Pollutant Monitor Labs Instrument | 46 |
| 10 | Data Summary, Ozone Pollutant Monitor Labs Instrument | 48 |
| 11 | Data Summary, $SO_2$ Pollutant Tracor Instrument | 50 |
| 12 | Data Summary, Sulfur Dioxide Plus Ozone Pollutant Tracor and Monitor Labs Instruments | 52 |
| 13 | Data Summary, $SO_2$ Pollutant Meloy Instrument | 55 |
| 14 | Effect of Permeation Chamber Flow Rate on Signal Response | 63 |
| 15 | Effect of $SO_2$ Permeation Tube Length | 65 |
| 16 | Effect of Cooling on Modified Bendix 8861P Calibrator | 67 |
| 17 | Effect of Heating on Modified Bendix 8861 Calibrator | 68 |

# 1.0 INTRODUCTION

The primary purpose of this task order was the support of the RAPS quality assurance effort. This task order was a logical extension of Task Order 58 under contract 68-02-1081. Under Task Order 58, quality assurance audits were conducted in support of the 1975 Summer Intensive on the RAPS helicopters, the MRI and Battelle airplanes, RTI and EMI vans, EPA aerosol trailer, RAMS stations, portable $O_3$ and CO monitors, and the gas chromatography laboratory.

In the initial scope of work of this task order, emphasis was placed on the preparation and deployment of various resources to perform calibrations and audits of air monitoring systems employed in the RAPS 1976 winter and summer field exercises. These resources consisted principally of a Winnebago Mobile Laboratory Van equipped with a complete complement of ambient air analyzers and a Bendix 8800 series portable calibrator. Subsequent modification to the task order included: an extension to provide audit coverage to the 1976 Fall Intensive, selected audits of local agency monitoring stations, a detailed study of the effect of the particulate filters on the RAMS analyzers, and a detailed study and modification of the Bendix portable calibrator.

## 2.0 SUMMARY

The work performed under this task order was divided into four major areas: first, preparation and calibration of the instrumentation and support equipment; second, audit of RAPS related instrumentation; third, modifications to the Bendix Model 8800 series calibrator; and fourth, special studies concerning the particulate filters on the RAMS analyzers intake lines. Also included as an appendix are the audit procedures developed for this task order.

Preparation of the Winnebago Mobile Van consisted primarily of modifications to the electrical system and improved apparatus for securing the instrumentation. Calibration curves were prepared for the Bendix 8861D calibrator. The system was first leak-checked and then calibrated using rising soap-film bubble meters. Data were converted to STP (0°C, 760 mm Hg, dry). Standards for analyzer calibrations were obtained either directly from the National Bureau of Standards (NBS) or traceable to NBS.

Field audits were performed in support of the RAPS 1976 Winter and Summer Intensives and of selected RAMS stations. Audit results are given in the text for RAMS stations, RAPS helicopters, Illinois agency sites, St. Louis City and County sites and other miscellaneous audits. In general, most instruments were good (errors within 15%); however, in selected cases results were poor (errors > 20%).

An extensive study was also conducted on the effects of the Teflon particulate filters placed in the inlet of the RAMS instruments measuring atmospheric pollutants. Both new and aged filters were studied under conditions of low and high relative humidity. Results indicate that: moist air alters the instrument response for NO, $O_3$, and $SO_2$; fresh filters tend to attenuate the results, particularly for ozone; and humidity did not affect instrument response to zero air.

A thorough investigation of the Bendix 8861 calibrator's performance in the delivery of $SO_2$ was conducted. NBS permeation tubes were used in studying flow rate over the tube, tube length, attitude of the permeation tube chamber and ambient temperature. A Meloy SA185 analyzer was used to monitor the results. As a result of this study, a new chamber was designed, fabricated, and installed in the calibrator to minimize leakage and provide adequate purge air temperature control.

## 3.0 QUALITY ASSURANCE AUDITS

The St. Louis Regional Air Pollution Study was conducted to develop, evaluate and validate air-quality simulation models on both regional and local scales covering urban and rural areas, and stationary and mobile pollution sources. For this reason, a comprehensive, accurate and readily retrievable data base of pollutants was developed for future model testing and validation. To guarantee the quality of the data, it was necessary to check the performance of the instruments used to make these pollution measurements.

The quality assurance program provided an in-depth audit of the instrumentation by checking the instruments with gases of known composition. Any discrepancy between the known gas composition and the concentration indicated by the instrument was logged and reported within twenty-four hours. Instruments which were checked included those at selected RAMS stations and those of various RAPS Special Experiments, such as the RAPS helicopters.

### 3.1 INSTRUMENTATION

The following instruments were used in this study:

1) Bendix 8861P
2) Bendix 8861D
3) Monitor Labs Model 8440 Oxides of Nitrogen Analyzer
4) Tracor Model 270HA Atmospheric Sulfur Analyzer
5) Meloy Model SA 185-2 Total Sulfur Analyzer
6) Bendix Ozone Monitor
7) Monitor Labs Model 8410 Ozone Analyzer
8) MRI Integrating Nephelometer
9) Rikadenki five pen recorder
10) Beckman 6800 Gas Chromotograph

Out of the above list, the following instruments were mounted in the Winnebago Van:

1) Monitor Labs Model 8440 Oxides of Nitrogen Analyzer
2) Tracor Model 270HA Atmospheric Sulfur Analyzer
3) Monitor Labs Model 8410 Ozone Analyzer
4) MRI Integrating Nephelometer
5) Rikadenki five pen recorder

## 3.2 VAN PREPARATION

To prepare the Winnebago Laboratory Van for field use it was first necessary to strip out all wiring and accessory internal batteries. It had been demonstrated during the previous intensive effort period that the use of batteries and an inverter to generate 115V power was unsatisfactory due to excessive current drain. The exterior-mounted ONAN power generator had been installed but power connections were incomplete.

All wiring was traced out and labelled and a color coded circuit diagram was prepared (Figure 1) showing all of the breaker panels, generators and switches necessary to the operation of the electrical system of the van. The system was made operational using either the self-contained 115 volt ONAN generator or 115 volts from an external source.

With this current configuration, a switch-over from generator to an external source (and vice versa) is awkward because of the power interruption. The system could be improved by the incorporation of a shorting-type transfer switch which would provide for an uninterrupted power transfer. This would eliminate the necessity of relighting burners and awaiting restabilization of the instruments which invariably drift when power is interrupted.

The Winnebago Laboratory Van was put in dependable running order. Both gas tanks were removed and cleaned, all fuel lines were blown clean and dried. The carburetor was rebuilt and readjusted. The carpet and draperies were cleaned and a vinyl runner was installed to decrease carpet wear and finally, the cabinets were covered with walnut grain contact paper to improve the appearance of the interior. The continuous gas analyzers were installed on a four inch thick styrofoam mattress pad and secured in place using a two

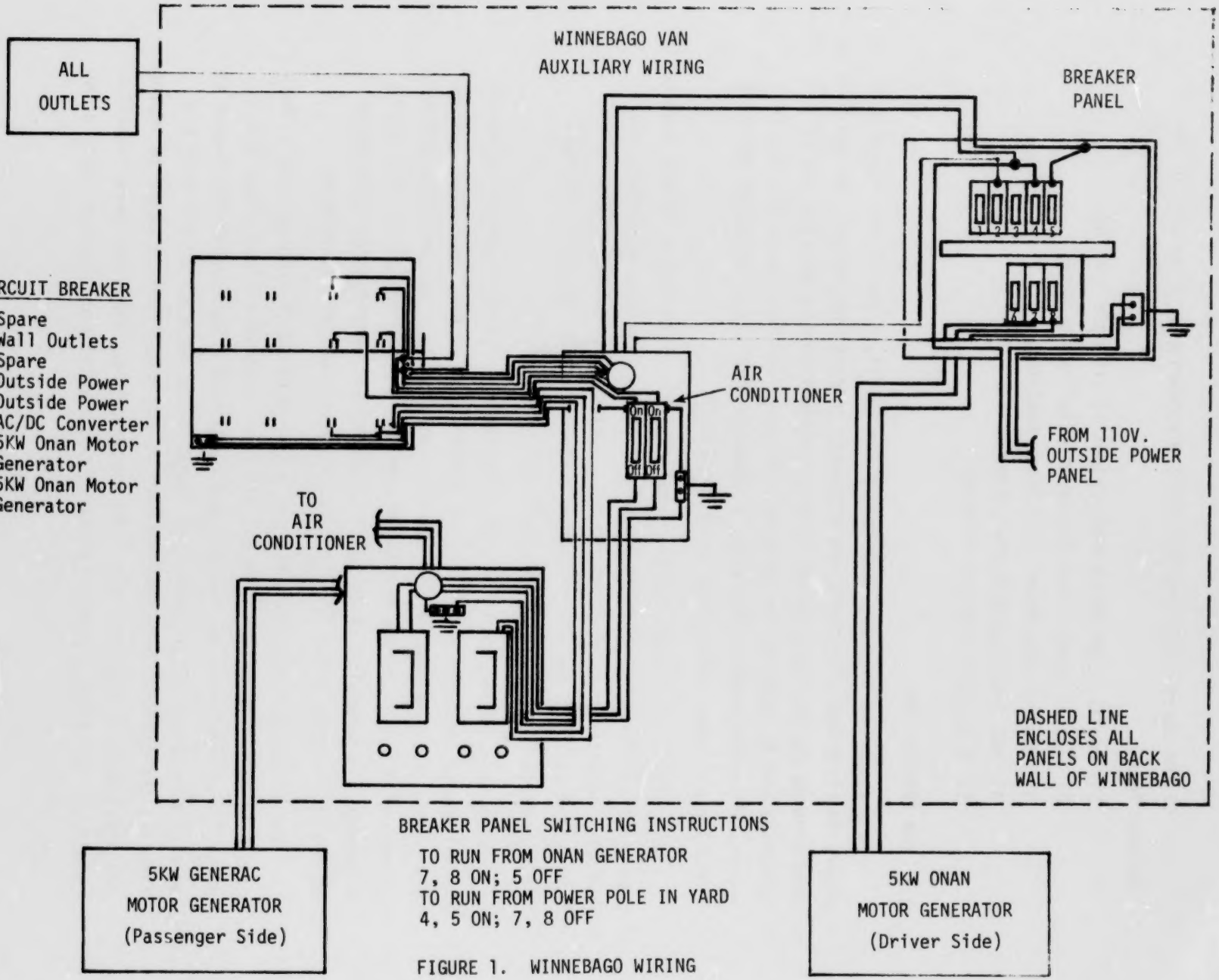



FIGURE 1. WINNEBAGO WIRING

inch square unistrut. A compression spring was incorporated in such a way that the instruments were held in place by spring compression (Figure 2). In addition to the continuous gas analyzers, the van was equipped with a wall mounted integrating nephelometer on separate manifold. A Bendix 8861 calibrator, a Meloy $SO_2$ analyzer, and an alternate ozone analyzer were deployed at various times during the course of audit activities on an as needed basis and configured accordingly. The Bendix 8861 calibrator was completely portable and was removed from the van and relocated on occasion as audit requirements dictated.

## 3.3 VAN OPERATION

The EPA Winnebago Mobile Laboratory Van was deployed to various field sites in the St. Louis area to perform audits of air monitoring systems employed in the RAPS 1976 Winter and Summer field expeditions and of selected RAMS stations. These audits were performed under the technical direction and, in many cases, in the presence of the EPA Task Coordinator. Scheduling of the audits was provided by the EPA Task Coordinator.

The audits were conducted using the Bendix 8861 portable calibration system. All spare equipment such as tubing, instrument parts, fittings, test instruments (DVM, portable recorders) were conveniently carried in the racks below the instrument shelf. The van was also used as a mobile laboratory when it became necessary to audit/calibrate instruments brought in for a check. When fully operational, audit/calibrations were possible for NO, $NO_2$, $NO_X$, $SO_2$, total sulfur, ozone, $CH_4$, THC, CO and light scatter. Audits of $CH_4$, THC and CO analyzers were generally accomplished utilizing standard gas cylinders and/or Teflon bags. When access to an (audit) analyzer was required, a Beckman 6800 located in the RAPS laboratory was deployed. Instrument output was observed using a Hewlett-Packard DVM and continuously monitored by connecting the output of each instrument to the Rikadenki recorder.

## 3.4 BENDIX PORTABLE CALIBRATOR

The equipment used during calibration/audit work consisted of a Bendix model 8861 portable calibration system capable of providing precise concentrations of $O_3$, $SO_2$, NO and $NO_2$. The 8861 system is composed of a model 8861P permeation tube assembly and a model 8861D dilution air/ozone generator

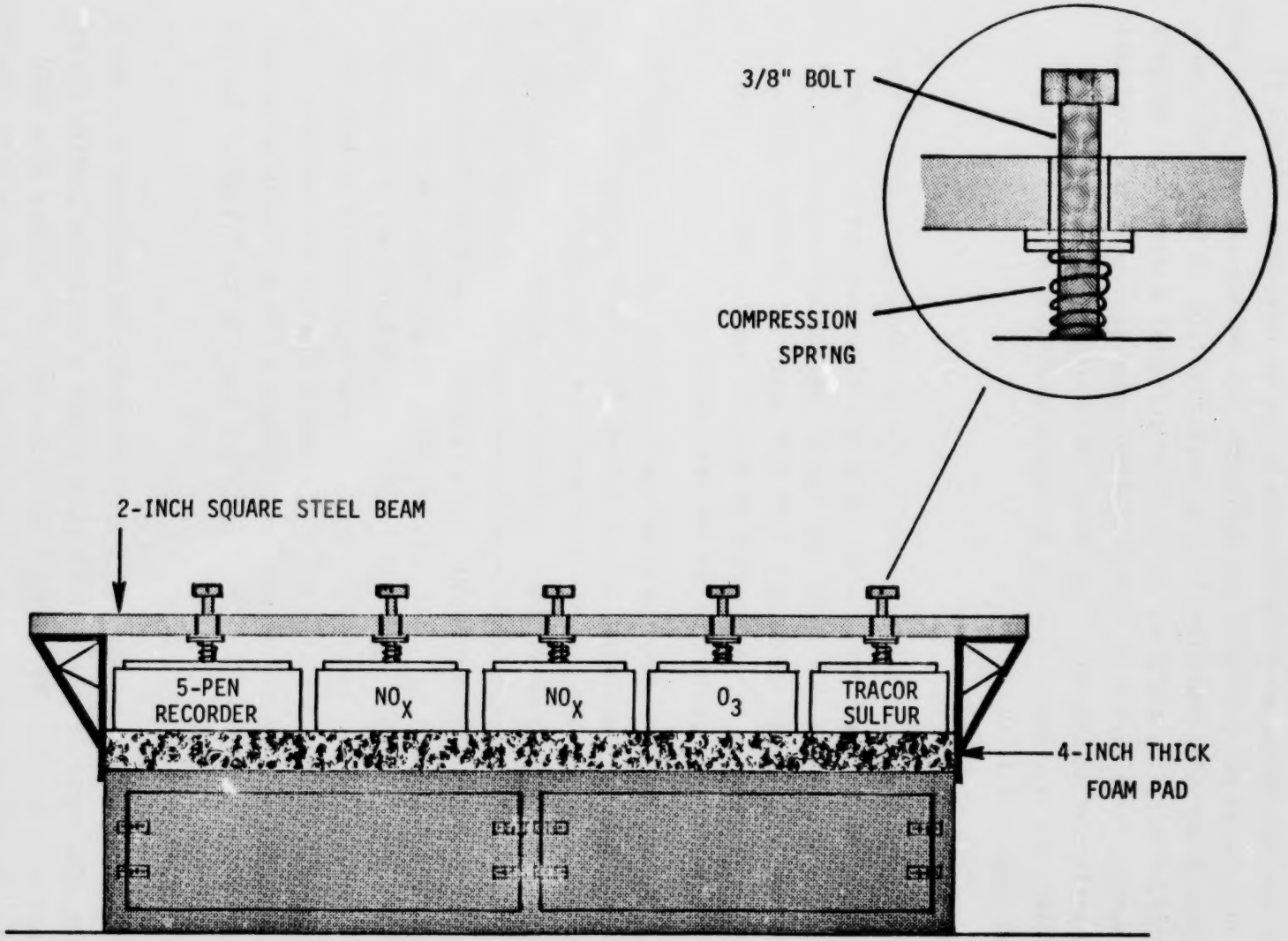



FIGURE 2. INSTALLATION OF INSTRUMENTS IN WINNEBAGO

assembly. The 8861 system is entirely self-contained within two aluminum carrying cases.

The 8861P permeation tube assembly consists of a permeation tube chamber, a pressure regulator/capillary flow system, temperature control circuitry, and a battery pack. Chamber temperature was maintained at 30°C $\pm$ .01°C either by line power during calibration work or by battery pack during transport. Chamber purge flow was provided by compressed air during calibration work or by a small aquarium pump during transport.

The 8861D dilution air/ozone generator assembly consists of a pump, an air drier, an air scrubber, pressure regulators, a series of temperature controlled flow orifices, mixing chambers, and a temperature controlled, constant current, ozone generator. Prior to use of the 8861D, it was necessary to develop calibration curves for the flow controlling orifices. Duplicate calibrations were performed at all available instrument pressures from 30-100% of gauge on each of the five orifices. Several orifice combinations were also calibrated yielding eight calibration curves in all.

All orifice calibrations were performed using the calibration train outlined in Figure 3. Initial leak checking of the 8861D was performed by sealing the outlet line of the 8861D and pressurizing. Leaks were located and eliminated with the aid of an in-line mass flow meter. Dry compressed air was then allowed to flow through the 8861D orifice under calibration and the exiting airflow rate was measured with a moving bubble flow meter. Since the soap film would add an unknown amount of water vapor to an otherwise dry air stream and introduce measurement error, the exiting air stream was saturated with water vapor before measurement. Following the determination of observed flow using the moving bubble flow meter, flow rates were corrected to standard conditions of 0°C and 760 mm Hg, dry basis. All calibration curves generated were maintained in the Bendix 8861D instruction manual.

Orifice calibrations were performed repeatedly during the course of the audit program to insure the integrity of the orifice calibration data in current usage. Typical calibration data is presented in Table 1. Typical calibration curves are presented as Figures 4-12.

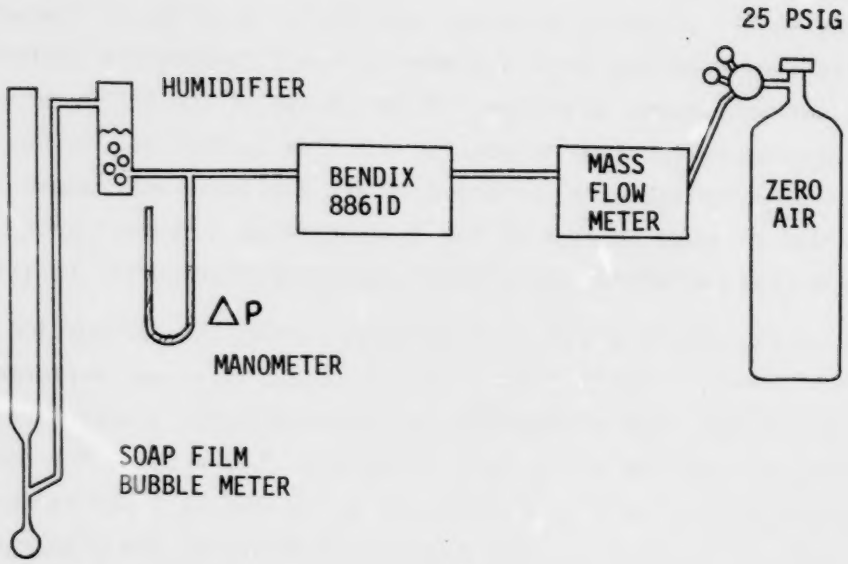



FIGURE 3. FLOW CALIBRATION EQUIPMENT

TABLE 1. BENDIX 8861 ORIFICE CALIBRATION DATA

ORIFICE NUMBER 1

| % Of Scale | Time For 1000 cc, seconds | Observed Flow cc/minute | Flow at Standard Conditions |
|---|---|---|---|
| 30 | 122.6 | 498.4 | 438.7 |
| 40 | 113.0 | 530.9 | 467.3 |
| 50 | 104.2 | 575.8 | 506.9 |
| 60 | 97.4 | 616.0 | 542.3 |
| 70 | 91.8 | 653.6 | 575.4 |
| 80 | 86.8 | 691.2 | 608.4 |
| 90 | 82.8 | 724.6 | 638.8 |
| 100 | 79.0 | 759.5 | 668.6 |

*Correction Factor = 0.88029

(continued)

$$* \; CF = \left[\frac{T_o}{T}\right] \times \left[\frac{P-Pw}{P_o}\right]$$

where $T_o$ = Standard Temperature (273.2 °K)

$T$ = Ambient Temperature; °K

$P$ = Ambient Pressure, mm Hg

$P_o$ = Standard Pressure (760 mm Hg)

$Pw$ = Partial pressure of water at ambient temperature T, mm Hg

Flow at Standard Conditions = CF x Observed Flow

TABLE 1 (continued)

| % Of Scale | Time For 1000 cc, seconds | Observed Flow cc/minute | Flow at Standard Conditions |
|---|---|---|---|
| | ORIFICE NUMBER 1 AND 2 | | |
| 30 | 61.2 | 980.4 | 863.0 |
| 40 | 56.0 | 1071.4 | 943.1 |
| 50 | 52.0 | 1153.8 | 1015.7 |
| 60 | 48.4 | 1239.7 | 1091.3 |
| 70 | 45.6 | 1315.8 | 1158.3 |
| 80 | 43.4 | 1382.5 | 1217.0 |
| 90 | 41.0 | 1463.4 | 1288.2 |
| 100 | 39.4 | 1522.8 | 1340.5 |
| | ORIFICE NUMBER 1 AND 3 | | |
| 30 | 40.8 | 1470.6 | 1294.5 |
| 40 | 37.4 | 1604.3 | 1412.2 |
| 50 | 34.8 | 1724.1 | 1517.7 |
| 60 | 32.6 | 1840.5 | 1620.2 |
| 70 | 30.8 | 1948.1 | 1714.9 |
| 80 | 29.2 | 2054.8 | 1808.8 |
| 90 | 27.8 | 2158.3 | 1900.0 |
| 100 | 26.6 | 2255.6 | 1985.6 |
| | ORIFICE NUMBER 1 AND 4 | | |
| 30 | 122.4 | 2451.0 | 2157.6 |
| 40 | 111.4 | 2693.1 | 2370.7 |
| 50 | 102.0 | 2941.2 | 2589.1 |
| 60 | 95.8 | 3131.5 | 2756.6 |
| 70 | 90.0 | 3333.3 | 2934.3 |
| 80 | 85.8 | 3496.5 | 3077.9 |
| 90 | 80.4 | 3731.3 | 3284.6 |
| 100 | 76.2 | 3937.0 | 3465.7 |

(continued)

TABLE 1 (continued)

| % Of Scale | Time For 1000 cc, seconds | Observed Flow cc/minute | Flow at Standard Conditions |
|---|---|---|---|
| | **ORIFICE NUMBER 1 AND 5** | | |
| 30 | 120.6 | 2487.6 | 2189.9 |
| 40 | 110.4 | 2717.4 | 2392.1 |
| 50 | 102.0 | 2941.2 | 2589.1 |
| 60 | 96.0 | 3125.0 | 2750.9 |
| 70 | 91.0 | 3296.7 | 2902.0 |
| 80 | 86.2 | 3480.3 | 3063.7 |
| 90 | 82.0 | 3658.5 | 3220.5 |
| 100 | 78.6 | 3816.8 | 3359.9 |
| | **ORIFICE 1, 2 AND 3** | | |
| 30 | 152.8 | 1963.3 | 1725.1 |
| 40 | 140.0 | 2142.8 | 1882.8 |
| 50 | 129.4 | 2318.4 | 2037.1 |
| 60 | 121.6 | 2467.1 | 2167.8 |
| 70 | 114.2 | 2627.0 | 2308.3 |
| 80 | 109.0 | 2752.3 | 2418.4 |
| 90 | 103.4 | 2901.4 | 2549.4 |
| 100 | 99.2 | 3024.2 | 2657.2 |
| | **ORIFICE 1, 2, 3 AND 4** | | |
| 30 | 77.0 | 3896.1 | 3423.4 |
| 40 | 70.6 | 4249.3 | 3733.8 |
| 50 | 65.0 | 4615.4 | 4055.4 |
| 60 | 61.2 | 4902.0 | 4307.3 |
| 70 | 58.0 | 5172.4 | 4544.9 |
| 80 | 55.2 | 5434.8 | 4775.5 |
| 90 | 52.6 | 5703.4 | 5011.5 |
| 100 | 50.0 | 6000.0 | 5272.1 |

(continued)

TABLE 1 (continued)

ORIFICE 1, 2, 3, 4 AND 5

| % Of Scale | Time For 1000 cc, seconds | Observed Flow cc/minute | Flow at Standard Conditions |
|---|---|---|---|
| 30 | 52.0 | 5769.2 | 5069.3 |
| 40 | 47.4 | 6329.1 | 5561.3 |
| 50 | 44.0 | 6818.2 | 5991.0 |
| 60 | 41.2 | 7281.6 | 6398.2 |
| 70 | 39.8 | 7537.7 | 6623.2 |
| 80 | 36.6 | 8196.7 | 7202.2 |
| 90 | 35.0 | 8571.4 | 7531.5 |
| 100 | 33.4 | 8982.0 | 7892.3 |

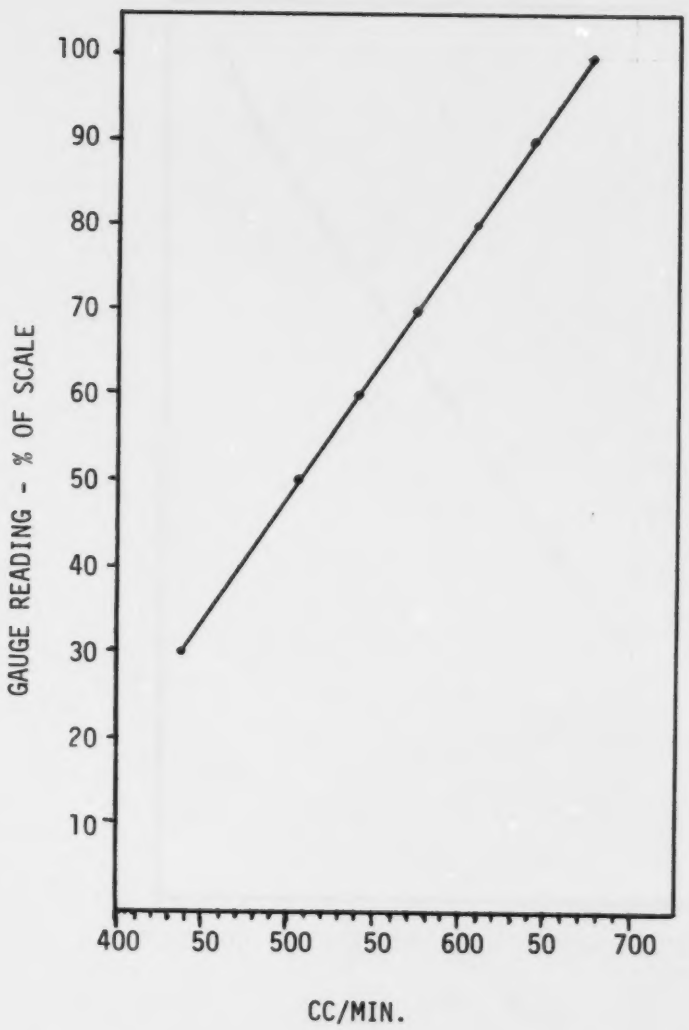



FIGURE 4. ORIFICE NO. 1 CALIBRATION CURVE

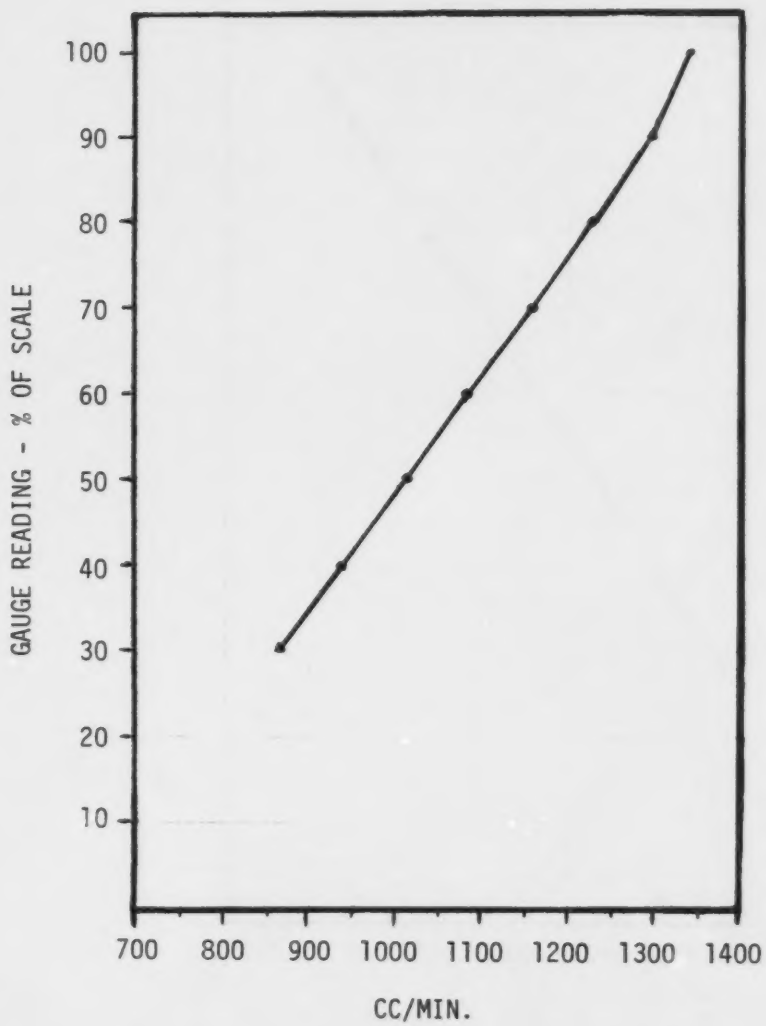



FIGURE 5. ORIFICES 1 AND 2 CALIBRATION CURVE

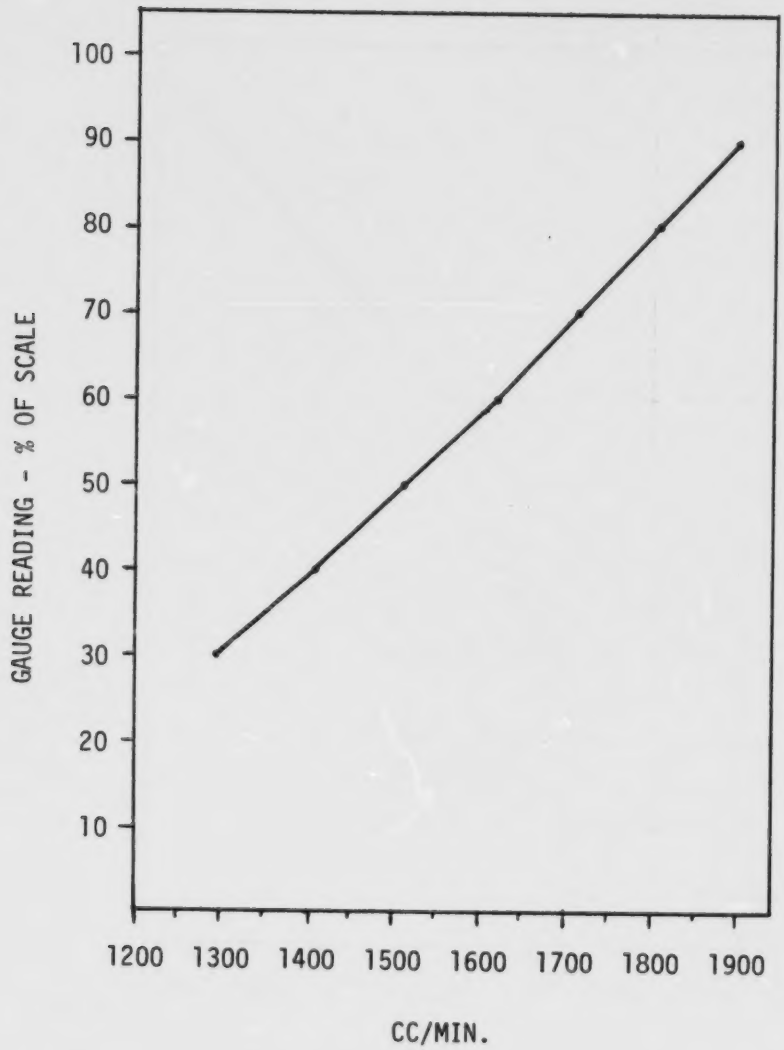



FIGURE 6. ORIFICES 1 AND 3 CALIBRATION CURVE

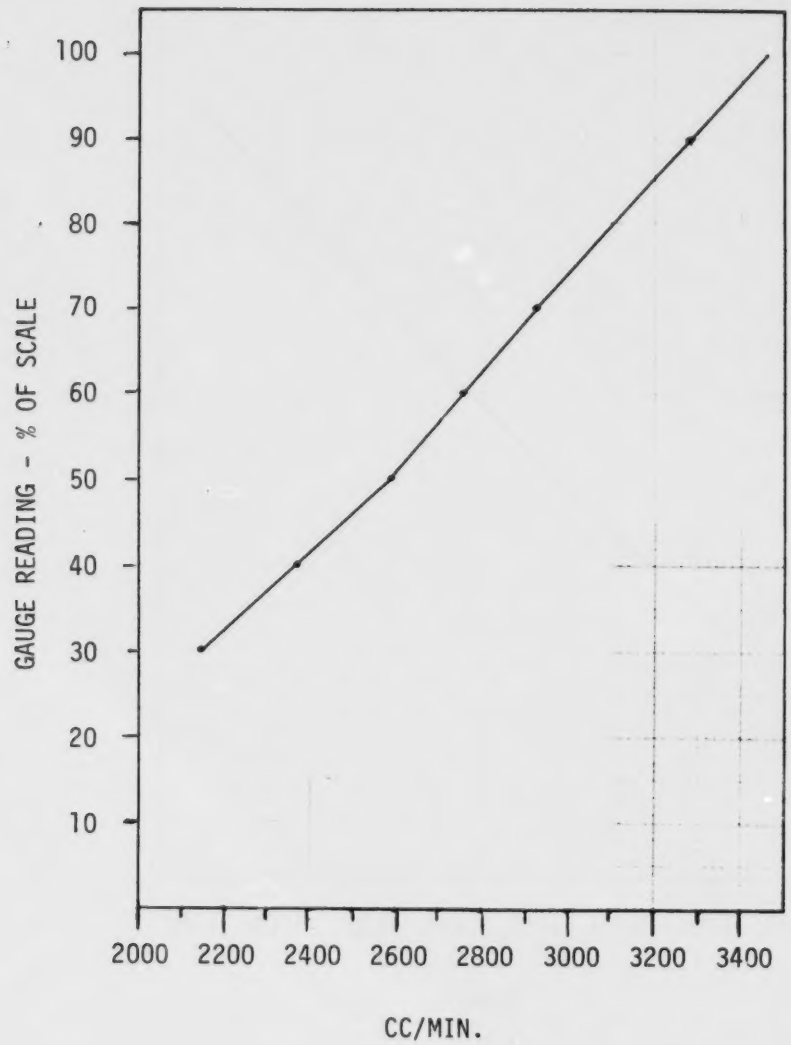



FIGURE 7. ORIFICES 1 AND 4 CALIBRATION CURVE

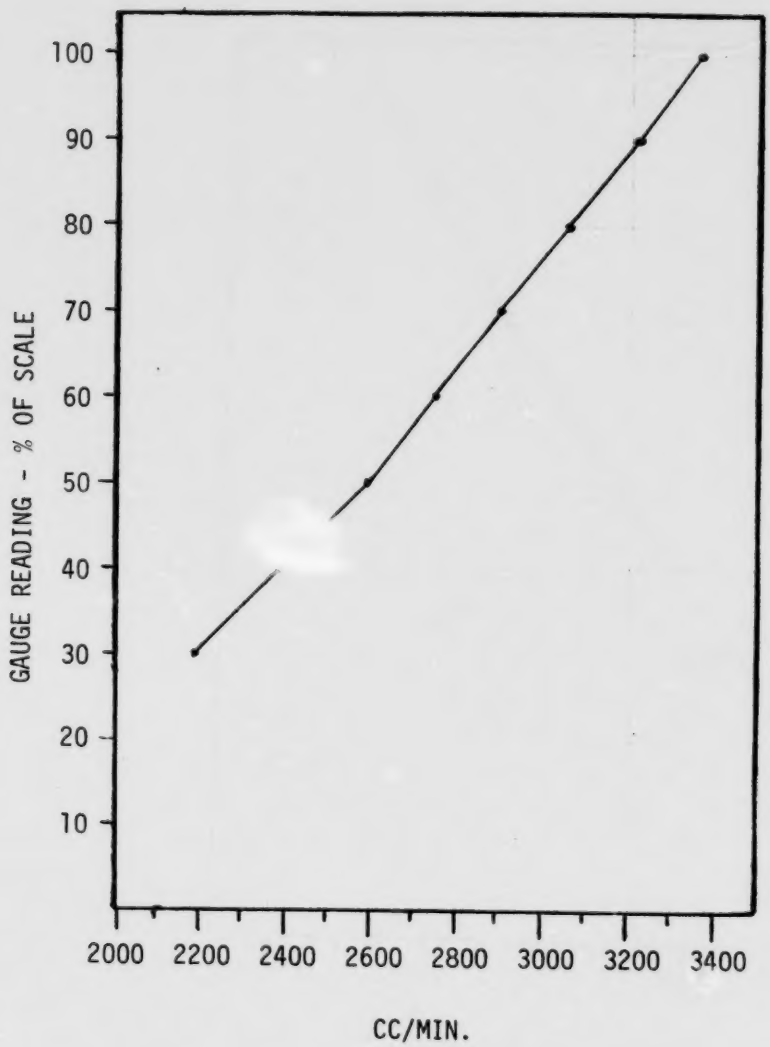



FIGURE 8. ORIFICES 1 AND 5 CALIBRATION CURVE

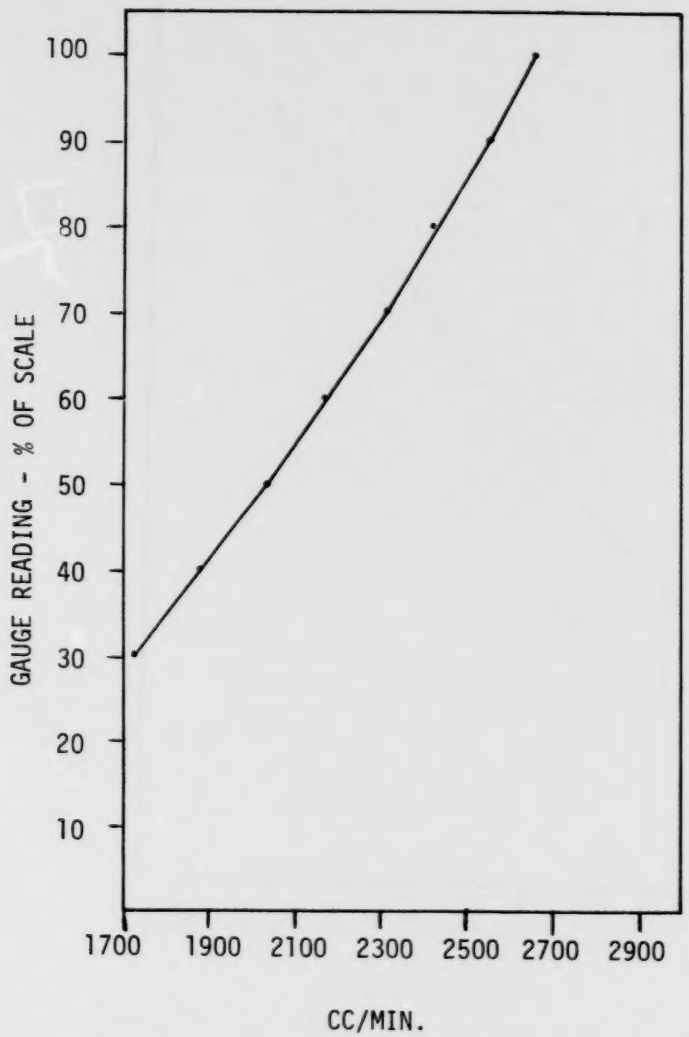



FIGURE 9. ORIFICES 1, 2 AND 3 CALIBRATION CURVE

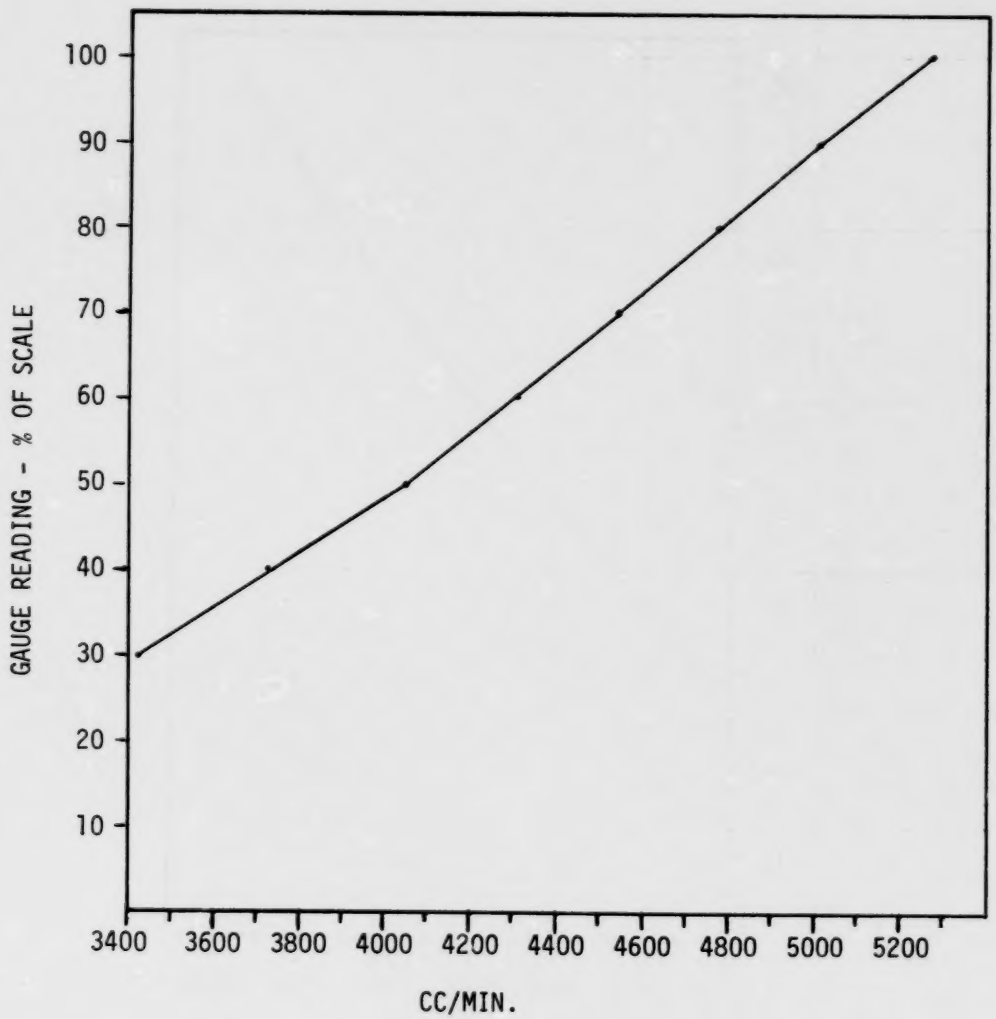



FIGURE 10. ORIFICES 1, 2, 3 AND 4 CALIBRATION CURVE

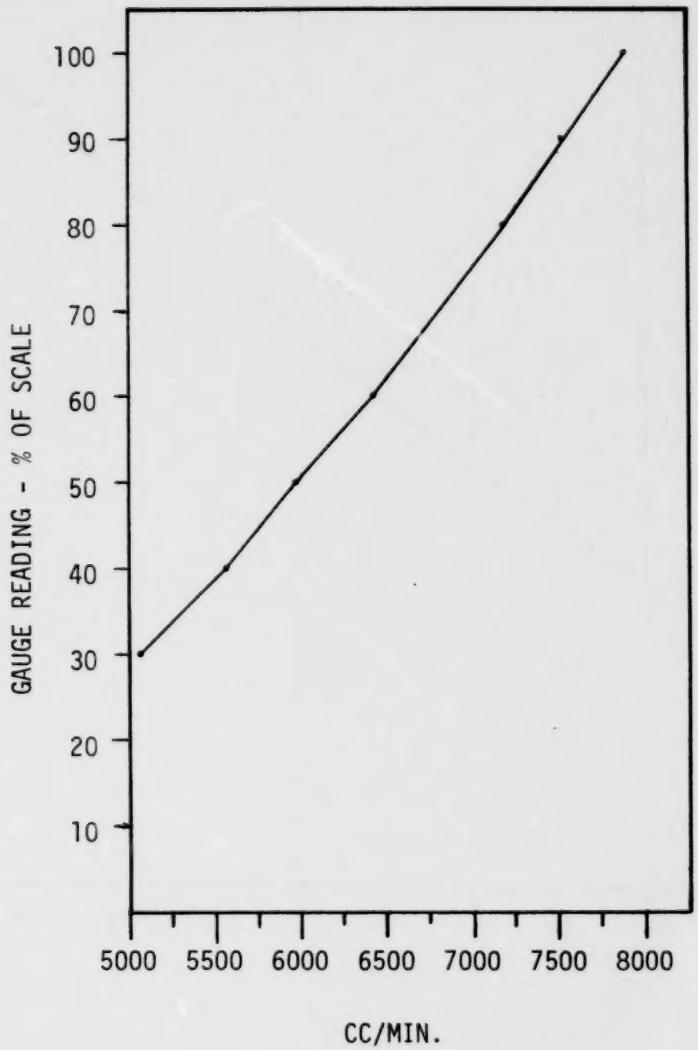



FIGURE 11. ORIFICES 1, 2, 3, 4 AND 5 CALIBRATION CURVE

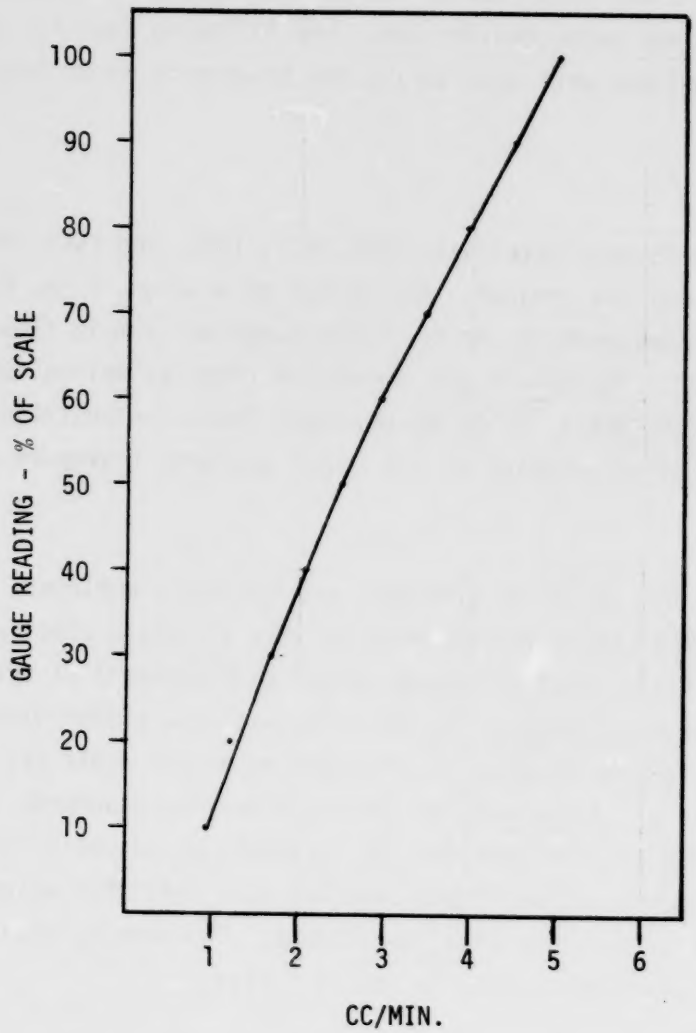



FIGURE 12. NO CAPILLARY CALIBRATION CURVE

## 3.5 AUDIT STANDARDS

The calibration standards employed during the course of the audit program were obtained either from the National Bureau of Standards (NBS) directly or from vendors supplying certification of analysis. In the latter case the vender's analysis was certified by the Environmental Protection Agency before the standard was submitted for use. The following specific gas sources and/or techniques were used during the program to assure quality in the audit standards.

### Sulfur Dioxide ($SO_2$)

NBS Standard Reference Materials (SRM) 1625, 1626, and 1627, were used exclusively throughout the project. The choise of a 10 cm, 5 cm, or 2 cm permeation tube was governed by the operating range and sample flow rate of the analyzer audited. The source gas permeation tube was maintained at constant temperature (30.00°C $\pm$ .05°C) during use. Audit concentrations were prepared by quantitative dilution of the source gas with ultrapure air.

### Nitric Oxide (NO)

NBS SRM 1684, 100 ppm NO in nitrogen, was typically employed. This cylinder was equipped with a low internal volume, stainless steel regulator which was routinely evacuated and purged prior to withdrawal of cylinder contents for audit gas preparation. The cylinder was used either directly by quantitative dilution and subsequent introduction of the audit gas to the analyzer under test or it was used to certify a working standard. In the latter case, the NBS cylinder was used to calibrate an oxides of nitrogen analyzer and a vendor-supplied NO standard was then certified by analysis under identical instrument operating conditions. The working standard, with NBS traceability, was then used during field audits.

### Nitrogen Dioxide ($NO_2$)

Nitrogen dioxide was generated by gas phase titration of nitric oxide. A constant-current, constant temperature, ozone generator within the portable calibrator served to provide the ozone for the titration. The procedure employed to accomplish the gas phase titration is described in Appendix A.

Ozone ($O_3$)

Ozone was generated within the portable calibrator as described above. The concentration produced was a function of lamp current and was routinely certified by gas phase titration of nitric oxide. The oxides of nitrogen analyzer aboard the van served to monitor each titration performed for the purpose of certifying the ozone concentration being delivered from the portable calibrator during an audit. Frequent pre-audit and post-audit certifications were performed to insure the integrity of the results obtained in the field.

Total Hydrocarbons (THC), Methane ($CH_4$), and Carbon Monoxide (CO)

THC, $CH_4$, and CO audit gas concentrations were derived from cylinders. Generally, the cylinders were vendor supplied and EPA certified. The standards were low level and prepared in air so that the cylinder contents could be introduced to an analyzer without prior dilution. The cylinders were either employed in the field with the contents introduced directly to the analyzer being audited, or used to prepare an audit gas sample in a Teflon bag. In the latter case, the bag was taken to analyzer to be audited and the contents introduced to the analyzer.

NBS SRM 1681, 1000 ppm CO in nitrogen was used on occasion to certify the contents of vendor supplied CO standards. NBS SRM 1658, 1659, and 1660, $CH_4$ standards in air, were not available during the course of the study.

Zero Air

The source of zero air most commonly used during audits was vendor supplied cylinder air certified by the vendor to meet the following specifications:

| | |
|---|---|
| THC (as $CH_4$) | < 10 ppb |
| CO | < 10 ppb |
| $NO_X$ | < 10 ppb |
| $SO_2$ | < 1 ppb |

This zero air was also used routinely as diluent air during the preparation of audit gas concentrations where dilution of a source gas was required.

On occasion, when an alternate source of dilution air was available, the alternate source was substituted as diluent after quality was verified by direct comparison to the cylinder gas. This practice was limited to audits involving $SO_2$, $NO_X$, and $O_3$. Audits involving THC, $CH_4$, and CO were performed using zero air obtained only from the zero air cylinders.

## 3.6 RESULTS AND DISCUSSION

Various field sites in the St. Louis area were audited. Audits of air monitoring systems employed in the RAPS 1976 winter and summer field expeditions and of selected RAMS stations were also performed. RAMS stations were audited in accordance with schedules provided by the EPA Task Coordinator. A written report of each audit was prepared on the day following the audit so that investigators could be advised of any errors discovered in their instrument systems.

Audits were run by supplying a carefully calibrated source gas to the instruments under test. Audits for ozone, NO-$NO_X$ and sulfur dioxide were performed using zero and four non-zero concentrations. Audits for CO, $CH_4$ and total hydrocarbons were performed using gases of known concentration supplied from a certified cylinder.

The results were recorded in tabular format. A typical data record is shown in Figure 13. For each instrument, the concentration of the calibration gas was recorded in the "Auditor Value" column. The corresponding instrument reading (in volts) was recorded in the next column. This voltage was translated into concentration using the applicable instrument transfer equation, which is of the general form

$$ppm = MX + b$$

In the case of RAMS stations, the coefficients M and b were obtained from the daily auto-calibration data reported in the station printouts.

For county and city stations, as well as helicopter instruments, the corresponding conversion factors were obtained from the respective personnel.

### 3.6.1 Data Analysis Methods

The instrument values were then compared to the audit values by calcu-

## STATION 111

Date: 6/25/76

NO

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| .450 | 4.2183 | .428 |
| ozone added | 1.4135 | .138 |
| .350 | 3.2324 | .326 |
| .250 | 2.2680 | .226 |
| .150 | 1.4184 | .138 |
| zero | .0683 | -.002 |

$NO_x$

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| .450 | 4.3505 | .442 |
| ozone added | 4.2431 | .430 |
| .350 | 3.3129 | .334 |
| .250 | 2.3364 | .233 |
| .150 | 1.4697 | .144 |
| zero | .0683 | -.011 |

$O_3$

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| .256 | 2.0825 | .229 |
| .215 | 1.7382 | .190 |
| .142 | 1.1938 | .128 |
| zero | .0708 | .000 |
| | | |
| | | |

$NO/NO_2$ CONVERTER EFFICIENCY: 96%

Instrument ppm = A+B (Auditor ppm)

| | | |
|---|---|---|
| A = -0.005 B = 0.951 | A = -0.011 B = 0.996 | A = .000 B = .886 |
| $r^2$= 0.999 $S_{y.x}$= 0.005 | $r^2$= 0.999 $S_{y.x}$= 0.006 | $r^2$= .9998 $S_{y.x}$= .002 |

$SO_2$

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

TOTAL SULFUR

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| .700 | 3.3077 | .614 |
| .500 | 2.2680 | .420 |
| .300 | 1.4111 | .261 |
| .150 | .6420 | .117 |
| zero | -.0048 | -.004 |
| | | |

CO

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| 40.60 | 3.8330 | 40.99 |
| 20.15 | 1.9213 | 20.50 |
| 3.43 | 1.6943 | 3.54 |
| 5.29 | 2.2705 | 4.78 |
| zero | .0463 | 0.018 |
| | | |

| | | |
|---|---|---|
| A = B = | A = -0.009 B = 0.880 | A = -0.120 B = 1.014 |
| $r^2$= $S_{y.x}$= | $r^2$= 0.999 $S_{y.x}$= 0.009 | $r^2$= 0.9997 $S_{y.x}$= 0.3195 |

$CH_4$

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| 2.20 | .9057 | 1.89 |
| zero | .0268 | -.062 |
| | | |
| | | |
| | | |
| | | |

TOTAL HYDROCARBONS

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| 2.20 | .8276 | 1.68 |
| zero | .0170 | -.041 |
| | | |
| | | |
| | | |
| | | |

NEPHELOMETER

| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
|---|---|---|
| .00-.03 | .36 | |
| .00-.03 | .016 | |
| 1.00±.03 | 2.566 | |
| 4.00±.25 | 10.61 | |
| | | |
| | | |

| | | |
|---|---|---|
| A = -.062 B = .887 | A = -.041 B = .782 | A = B = |
| $r^2$= $S_{y.x}$= | $r^2$= $S_{y.x}$= | $r^2$= $S_{y.x}$= |

FIGURE 13. TYPICAL AUDIT DATA RECORD

Reproduced from best available copy.

lating the coefficient of a linear regression equation between the two sets of values using a linear regression program of a Hewlett-Packard 65 calculator. The equations used were

$$A = \frac{\Sigma y_i}{n} - B\left(\frac{\Sigma x_i}{n}\right)$$

and

$$B = \frac{\Sigma x_i y_i - \frac{\Sigma x_i \Sigma y_i}{n}}{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}$$

where

| | | |
|---|---|---|
| A | = | intercept of regression line |
| B | = | slope of regression line |
| $x_i$ | = | audit gas concentration i |
| $y_i$ | = | instrument reading i |
| n | = | number of observations |

As used here, the symbol $\Sigma$ means summation of values following the symbol for index values, i, from 1 to n.

In addition, the square of the correlation coefficient, $r^2$, was determined, which measures the degree of fit of the points to the least squares straight line. When $r^2 = 1$, the correlation is said to be perfect, with all points falling on the regression line. When $r^2 = 0$, the relationship between the two variables, x and y, is completely random.

The equation used by the program to determine $r^2$ is

$$r^2 = \frac{\left[\Sigma x_i y_i - \frac{\Sigma x_i \Sigma y_i}{n}\right]^2}{\left[\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}\right]\left[\Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}\right]}$$

The coefficient B, the slope of the regression curve, is an indication of the accuracy of the instrument under test (assuming that the auditor values are unbiased). A slope of 1.000 indicates complete correspondence, a slope of 1.0500 or .9500 indicates a concentration or instrument dependent error of +5% and -5% respectively in the instrument under test.

## TABLE 2. DATA SUMMARY - RAMS STATIONS

| POLLUTANT | | NO | | | $NO_X$ | | | $NO_2$ CONVERTER | $O_3$ | | | $SO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | A | B | $r^2$ | A | B | $r^2$ | EFFICIENCY, % | A | B | $r^2$ | A | B | $r^2$ |
| 120* | 2/14 | -.0043 | .9558 | .9996 | -.0068 | .9910 | .9995 | 94.0 | .0086 | .7880 | .9956 | -.0012 | .7700 | .9952 |
| 101* | 2/20 | -.0035 | 1.0535 | .9997 | -.0067 | 1.0772 | .9990 | 98.5 | -.0038 | .9537 | .9990 | -.0049 | 1.2096 | .9865 |
| 111** | 6/25 | -.0051 | .9513 | .9992 | -.0108 | .9965 | .9992 | 96.0 | .0004 | .8885 | .9997 | | | |
| 112** | 6/28 | -.0042 | 1.0049 | .9997 | .0000 | 1.1723 | .9999 | 100.0 | .0000 | .8670 | .9998 | | | |
| 114* | 6/29 | -.0007 | 1.0506 | .9999 | -.0007 | 1.0747 | .9998 | 99.0 | .0008 | 1.0096 | .9999 | | | |
| 104* | 6/30 | -.0196 | 1.0302 | .9738 | -.0030 | .9613 | .9566 | 98.0 | .0000 | .8550 | .9999 | | | |
| 107** | 7/1 | | | | | | | | .0020 | .9070 | .9999 | | | |
| 120 | 7/2 | -.0009 | 1.0596 | .9996 | .0027 | 1.0344 | .9994 | 101.0 | .0026 | 1.0127 | .9987 | | | |
| 112 | 7/19 | .0002 | 1.0260 | .9999 | .0007 | 1.1841 | .9998 | | .0030 | .9626 | .9990 (1) | | | |
| 114 | 8/17 | .0004 | .8943 | .9997 | -.0020 | .9277 | .9998 | 97.9 | .0021 | .9475 | .9990 | | | |
| 111 | 8/18 | -.0018 | 1.0015 | .9997 | -.0032 | 1.0135 | .9997 | 98.7 | .0033 | 1.0140 | .9961 | | | |
| 104 | 8/19 | -.0010 | .8959 | .9998 | .0007 | .8971 | .9997 | 98.5 | .0008 | .9121 | .9953 | (2) .0006 | 1.0070 | .9990 |
| 115* | 11/5 | -.0010 | 1.0082 | .9999 | -.0005 | .9861 | .9998 | 96.6 | .0036 | .9300 | .9972 | (2) -.0276 | 1.0200 | .9968 |
| 125** | 11/11 | -.0017 | .9469 | .9998 | -.0085 | .9567 | 1.0000 | 99.3 | .0041 | .9540 | .9989 | | | |
| 101 | 11/12 | -.0010 | 1.0200 | .9998 | -.0017 | 1.0240 | .9997 | 99.3 | .0016 | .8669 | .9989 | (2) .0026 | .9010 | .9987 |
| 102** | 11/18 | .0029 | 1.0163 | .9998 | -.0012 | 1.0746 | .9933 | | .0024 | .9900 | .9991 | | | |
| MEAN | | | .9944 | | | 1.0247 | | | | .9287 | | | .9815 | |
| STANDARD DEVIATION | | | .0532 | | | .0815 | | | | .0646 | | | .1623 | |

(1) Audit performed 7/23/77

(2) High range

* Tracor Sulfur analyzer

** Meloy Sulfur analyzer

(continued)

## TABLE 2 (continued)

| POLLUTANT | | TOTAL SULFUR | | | TOTAL HYDROCARBON | | | $CH_4$ | | | CO | | | AMBIENT T, °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STATION | DATE | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | DURING AUDIT |
| 120* | 2/14 | .0017 | .6757 | .9952 | .0652 | .7513 | .9999 | .0093 | .7394 | .9997 | .0082 | .7957 | | 22.9 |
| 101* | 2/20 | -.0046 | 1.1863 | .9889 | -.0807 | .9026 | .9978 | -.2670 | .9006 | .9998 | .0601 | .9063 | .9963 | - |
| 111** | 6/25 | (2) -.0088 | .8799 | .9989 | -.0410 | .7820 | | -.0620 | .8870 | | -.1200 | 1.0140 | .9997 | - |
| 112** | 6/28 | (2) -.0033 | .8459 | .9997 | .0020 | .8450 | | -.0630 | .9240 | | -.0850 | 1.0850 | .9990 | - |
| 114* | 6/29 | | | | .0140 | .9710 | | .0110 | .9270 | | -.2270 | 1.1170 | .9998 | - |
| 104* | 6/30 | | | | .0010 | .9590 | | .0230 | .9670 | | .1170 | 1.0960 | .9999 | - |
| 107** | 7/1 | (2) -.0045 | .7567 | .9997 | -.0220 | .8560 | | -.0500 | .8860 | | -.2730 | 1.0380 | .9998 | - |
| 120 | 7/2 | | | | | | | | | | | | | |
| 112 | 7/19 | (2) .0055 | .7936 | .9996 | .0200 | 1.0280 | | -.0150 | .9610 | | .0040 | .9481 | 1.0000 | 21.6 |
| 114 | 8/17 | | | | .0060 | .8791 | | .0200 | .8773 | | .0107 | 1.0085 | | - |
| 111 | 8/18 | (2) .0112 | .8850 | .9976 | -.0040 | .8518 | | .0030 | .8986 | | .0996 | .9334 | .9898 | - |
| 104 | 8/19 | (2) .0036 | .9005 | .9988 | -.0130 | 1.0014 | | -.0240 | .9836 | | .0681 | 1.0367 | .9913 | - |
| 115* | 11/5 | (2) .0192 | .8780 | .9980 | .0217 | 1.0743 | .9995 | -.0766 | 1.0413 | .9996 | (2) .0550 | .8769 | | - |
| 125** | 11/11 | | | | .1496 | .9129 | .9996 | .0419 | .8932 | .9996 | -.0006 | .8954 | .9999 | - |
| 101 | 11/12 | (2) .0020 | .8710 | .9981 | .0242 | .9934 | .9999 | -.0358 | .9929 | .9999 | -.0120 | .9377 | .9984 | - |
| 102** | 11/18 | (2) .0334 | .9050 | .9909 | .0486 | 1.0001 | 1.0000 | .0176 | .9977 | 1.0000 | (2) -.2299 | 1.0043 | .9987 | - |
| MEAN | | | .8706 | | | .9205 | | | .9251 | | | .9795 | | |
| STANDARD DEVIATION | | | .1263 | | | .0933 | | | .0717 | | | .0905 | | |

(1) Audit performed 7/23/76

(2) High range

* Tracor Sulfur analyzer

** Meloy Sulfur analyzer

# TABLE 3. RAPS HELICOPTERS

| POLLUTANT | NO | | | $NO_X$ | | | $NO_2$ CONVERTER | $O_3$ | | | TOTAL SULFUR | | | CO | | | AMBIENT T, °C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | $r^2$ | A | B | $r^2$ | EFFICIENCY, % | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | DURING AUDIT |
| RAPS HELICOPTER DATE | | | | | | | | | | | | | | | | | |
| No. 95958 (1) 2/16 | .0004 | .8589[a] | .9989 | .0089 | .8377[a] | .9992 | - | | | | -.0112 | 1.2300[c] | .9972 | | | | 20.2 |
| No. 95958 (1) 2/17 | .0036 | .9270[a] | .9990 | -.0022 | .9512[a] | .9993 | - | -.0011 | .9750[b] | .9947 | | | | 1.0500 | .9452[r] | | 19.4 |
| No. 87934 (1) 2/24 | -.0022 | .9605[a] | .9994 | -.0045 | .9688[a] | .9994 | - | -.0077 | .7436[b] | .9923 | .0115 | 1.1426[c] | .9980 | | | | 22.3 |
| No. 95958 (1) 3/1 | -.0023 | .9934[a] | .9994 | -.0057 | .9863[a] | .9989 | 98.0 | .0042 | .9449[b] | .9970 | -.0282 | .9093[c] | .9914 | .7899 | .9125[r] | .9986 | 28.3 |
| No. 95958 (2) 3/11 | -.0038 | 1.0407[a] | .9995 | -.0047 | 1.0384[a] | .9993 | 98.0 | .0018 | .8198[b] | .9995 | .0233 | 1.2920[c] | .9960 | -.0126 | .9660[r] | .9997 | 21.9 |
| No. 87934 (2) 7/14 | .0016 | .9798[a] | .9998 | .0030 | .9509[a] | .9992 | 99.0 | .0096 | .9660[b] | .9997 | -.0020 | 1.0593[c] | .9997 | 2.7873 | .9287[r] | 1.0000 | 28.5 |
| No. 87934 (1) 7/15 | .0017 | .9503[a] | .9999 | .0037 | .9439[a] | .9979 | - | .0146 | 1.1350[b] | .9991 | -.0018 | 1.0532[c] | .9999 | 1.7725 | .8748[r] | .9999 | 23.8 |
| No. 95954 (1) 7/27 | -.0001 | .9372[a] | .9991 | .0008 | .9340[a] | .9996 | 102.0 | .0030 | .7957[b] | .9906 | -.0028 | .8850[c] | .9988 | 3.1970 | .9028[r] | .9995 | - |
| No. 87934 (1) 8/9 | -.0135 | .8609[a] | .9965 | -.0010 | .9132[a] | .9999 | 103.0 | -.0083 | 1.1104[b] | .9980 | -.0037 | .8811[c] | .9983 | | | | - |
| No. 87934 (2) 8/10 | -.0111 | .8484[a] | .9995 | -.0041 | .9122[a] | .9996 | 100.0 | -.0075 | 1.0624[b] | .9991 | .0034 | .8460[c] | .9988 | | | | - |
| No. 95958 (1) 10/31 | .0013 | .9929[a] | .9999 | .0046 | 1.0093[a] | .9996 | 97.3 | .0036 | 1.1530[b] | .9988 | .0002 | .5651[c] | .9995 | | | | - |
| No. 95958 (2) 11/1 | -.0016 | 1.0406[a] | .9997 | .0119 | 1.0236[a] | .9996 | 96.7 | .0018 | 1.1420[b] | .9995 | .0013 | .5569[c] | .9993 | .4071 | .8661[s] | .9999 | - |
| No. 95958 (1) 11/7 | -.0027 | 1.0488[a] | .9994 | .0013 | 1.0547[a] | .9986 | 88.2 | .0004 | 1.0960[b] | .9996 | .0078 | .8445[c] | .9984 | 1.7130 | .9223[s] | .9958 | - |
| No. 95958 (2) 11/8 | -.0011 | 1.1131[a] | .9999 | .0026 | 1.0966[a] | .9995 | 96.7 | -.0003 | .9700[b] | .9997 | .0088 | .8050[c] | .9969 | 1.5420 | .9530[s] | .9997 | - |
| No. 95958 (1) 11/14 | .0002 | 1.0874[a] | .9998 | .0001 | 1.0855[a] | .9999 | 98.6 | .0026 | 1.3006[b] | .9991 | .0090 | .8340[c] | .9985 | .7990 | .9832[s] | .9979 | - |
| MEAN | | .9760 | | | .9804 | | | | 1.0153 | | | .9230 .8348** | | | .9255 | | |
| STANDARD DEVIATION | | .0817 | | | .0712 | | | | .1569 | | | .2168 .1682** | | | .0379 | | |

a = Monitor Labs 8840 NO-$NO_X$

b = REM Scientific Co. Ozone Analyzer - Model 612B

c = Meloy Model SA160R

r = Beckman DIF 7000 CO Analyzer

s = Andros CO Analyzer

HELICOPTERS

No. 87934 = RAPS 1

No. 95954 = RAPS 2

No. 95958 = RAPS 3

(1) Pre-flight audit

(2) Post-flight audit

* Sulfur analyzer results may be seriously affected by the absence of $CO_2$ in the audit gas mixture

** Recomputed omitting first four sulfur audits

## TABLE 4. ST. LOUIS CITY AND COUNTY STATIONS

| POLLUTANT | | NO | | | $NO_X$ | | | $O_3$ | | | TOTAL SULFUR | | | TOTAL HYDROCARBONS | | | CO | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ |
| CITY | DATE | | | | | | | | | | | | | | | | | | |
| Sta. No. 4 | 6/7 | .0036 | .6508[m] | .9672 | .0097 | .0237[m] | .8305 | | | | | | | .3000 | .8640 | | 7.5680 | .9350 | .9990 |
| Sta. No. 1 | 6/8 | | | | | | | | | | .1592 | .9051[o] | .9973 | .2000 | .7730 | | 5.1500 | 1.4900 | .9990 |
| Sta. No. 5 | 6/9 | .0000 | .9500[m] | .9918 | | | | | | | .1210 | 1.1979[o] | .9984 | .0000 | .9090 | | 6.1980 | 1.0560 | .9980 |
| Sta. No. 3* | 6/10 | .0186 | .3949[m] | .9883 | .0256 | .0085[m] | .1412 | | | | .1010 | 1.1990[o] | .9910 | .3000 | .6820 | | 7.1720 | 1.1020 | .9990 |
| Sta. No. 2* | 6/11 | .0040 | .4740[m] | .5820 | .0370 | .0470 | .1580 | | | | .0665 | 1.4070[o] | .9938 | | | | 8.7900 | 1.2480 | 1.0000 |
| Sta. No. 3 | 9/8 | | | | | | | .0055 | 1.0930[e] | .9989 | | | | .1000 | .5450 | | 4.7190 | 1.1163 | .9996 |
| Sta. No. 2 | 9/8 | | | | | | | .0050 | 1.6630[f] | 1.0000 | | | | | | | 4.5100 | 1.1281 | 1.0000 |
| COUNTY | DATE | | | | | | | | | | | | | | | | | | |
| Sta. No. 6* | 6/15 | .0000 | .1430[m] | | .0000 | .2200 | | | | | .0057 | .7425[l] | .9775 | .2500 | .4550 | | 1.8700 | 1.0090 | .9902 |
| Sta. No. 9* | 6/17 | .0000 | .0670 | | .0130 | .1570 | | | | | | | | .1000 | .9090 | | .6770 | 1.1100 | .9960 |
| Sta. No. 7* | 6/18 | .0000 | .1570 | | .0040 | .0170 | | | | | .0000 | .6670 | | .2000 | 1.0910 | | 3.1710 | 1.3140 | .9412 |
| Sta. No. 8 | 6/21 | .0000 | .6270 | | .0080 | .0000 | | | | | .0000 | .3870 | | .0000 | .8860 | | .0000 | 1.1950 | |
| Sta. No. 6 | 8/25 | | | | | | | .0088 | .7628[n] | .9978 | | | | | | | 1.6020 | 1.0950 | .9994 |
| Sta. No. 7 | 8/26 | | | | | | | .0031 | .8281[n] | .9975 | | | | | | | 2.4110 | .8759 | .9852 |
| MEAN | | | .4330 | | | .0676 | | | 1.0867 | | | .9294 | | | .7904 | | | 1.1288 | |
| STANDARD DEVIATION | | | .3047 | | | .0858 | | | .4099 | | | .3586 | | | .1993 | | | .1599 | |

e = Bendix Ozone Analyzer
f = MEC Ozone Analyzer Model 1100
l = Technicon $SO_2$ Analyzer (breadboard construction)
m = Technicon NO Analyzer (breadboard construction)
n = Monitor Labs Model 8410 Ozone Analyzer
o = Davis Model 11-7000 $SO_2$ Analyzer
* $NO_X$ Analyzer response extremely slow

## TABLE 5. ILLINOIS STATIONS

| POLLUTANT | | NO | | | CO | | | $O_3$ | | | $SO_2$ | | | TOTAL SULFUR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ |
| STATION | DATE | | | | | | | | | | | | | | | |
| East St. Louis | 6/1 | | | | | | | | | | -.0309<br>.0640 | 1.0463[m]<br>.8750[p] | .9649<br>1.0000 | .0639 | .8751[p] | 1.0000 |
| Cahokia Mounds | 6/1 | | | | 2.4600 | .8130 | 9960 | | | | .0295 | .9414[m] | .9993 | | | |
| Alton | 6/3 | | | | | | | | | | -.0293 | .9889[m] | .9759 | | | |
| Wood River | 6/3 | | | | 2.3330 | .8490 | .9996 | | | | .0417 | .9266[m] | .9764 | | | |
| Wood River | 9/10 | | | | | | | .0026 | 1.0003[d] | .9997 | | | | | | |
| Cahokia Mounds | 9/10 | | | | | | | -.0009 | .9800[d] | .9996 | | | | | | |
| MEAN | | | | | | .8310 | | | .9902 | | | .9556 | | | | |
| STANDARD DEVIATION | | | | | | .0254 | | | .0144 | | | .0649 | | | | |

d = Dasibi Model 1003AH Ozone Analyzer
m = Technicon IV $SO_2$ Analyzer
p = Philips $SO_2$ Analyzer

# TABLE 6. MISCELLANEOUS AUDITS

| POLLUTANT | | NO | | | $NO_x$ | | | $O_3$ | | | $SO_2$ | | | TOTAL HYDROCARBONS | | | $CH_4$ | | | CO | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATE | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ | A | B | $r^2$ |
| Da Vinci* | 7/9 | | | | | | | .0006 | 1.0266 | .9995 | .0211 | .7869[i] | .9966 | | | | | | | | | |
| MRI Cessna | 7/10 | .0008 | 1.0185[a] | .9991 | .0004 | 1.0166[a] | .9995 | .0082 | .7655[b] | .9994 | -.0334 | 1.0925[j] | .9996 | | | | | | | | | |
| RAPS G.C. Lab | 7/22 | | | | | | | | | | | | | .1993 | .9818 | | -.1250 | 1.0477 | | -.0525 | 1.0561 | .9999 |
| Univ. Van Minnesota | 7/24 | | | | | | | .0090 | .9590[d] | .9996 | .0094 | .7805[k] | .9944 | | | | | | | | | |
| MRI Cessna** | 7/25 | .0201 | .6064[a] | .8973 | .0171 | .7946[a] | .9659 | .0015 | .9544[b] | .9970 | .0422 | 1.2650[j] | .9986 | | | | | | | | | |
| Da Vinci* | 7/28 | | | | | | | .0000 | 1.0120[d] | .9999 | .0422 | .7695[i] | .9994 | | | | | | | | | |
| Chaney Laser | 7/29 | | | | | | | .0033 | .9385[h] | .9985 | | | | | | | | | | .0360 | .6492 | .9882 |
| Chaney Laser | 7/29 | | | | | | | .0048 | 1.2189[h] | .9990 | | | | | | | | | | | | |
| McElroy Van SIGN-X | 8/2 | | | | | | | | | | .0740 | .4600[g] | .9950 | | | | | | | | | |
| McElroy Helicopter SIGN-X | 8/6 | | | | | | | | | | .0630 | .6510[g] | .9980 | | | | | | | | | |

a = Monitor Labs 8440 $NO$-$NO_x$

b = REM Scientific Co. Ozone Analyser - Model 612B

d = Dasibi Model 1003AH Ozone Analyzer

g = SIGN-X $SO_2$ Analyzer Model 604E

h = A.I.D. portable ozone analyzer (two analyzers audited)

i = TECO Thermo Electron Corp. Series 43

j = Theta Sensors Inc. Model LS-400A $SO_2$ Analyzer

k = Monitor Labs Model 8450 $SO_2$ Analyzer

* Reported instrument meter readings

** Severe instrument drift in $NO$-$NO_x$ analyzer

3.6.2 AUDIT RESULTS

Tables 2-6 give the results for the audits of RAMS station instruments, RAPS helicopter instruments, St. Louis City and County stations, Illinois EPA stations, and miscellaneous audits.

Audits of the RAMS station instruments indicate that

1. The Monitor Lab NO $NO_X$ instruments show an average slope of .9944, with a standard deviation of only .0532 for NO. For $NO_X$ the slope is 1.0247, the SD is somewhat larger at .0815. With one exception, $NO_2$ converter efficiency was found to be 97% or better.

2. The Monitor Labs ozone instruments show a somewhat lower slope with audit values .9287, with a SD of .0646.

3. The Tracor sulfur dioxide instrument gave an average slope of .9815. However, this number is somewhat misleading since individual instruments were off by large amounts, as indicated by an SD of .1623.

4. The total sulfur measurments from the Meloy and Tracor instruments gave a rather low average slope of .8706 with a SD of .1263. The Tracor $SO_2$ analyses were generally in closer agreement with the audit test gas values.

5. The Beckman 6800 total hydrocarbon analyzers gave an average slope of .9205 with a SD of .0933.

6. The Beckman 6800 methane analyzers gave an average slope of .9251 with a SD of .0717.

7. The Beckman 6800 carbon monoxide analyzers gave an average slope of .9795 with a SD of .0905.

Helicopter audits are summarized in Table 3. The results are similar to those obtained at the RAMS stations.

1. The Monitor Labs recorders gave an average slope of .9760 for NO, .9804 for $NO_X$. The standard deviations were .0817 and .0712, respectively. These results compare well with the RAMS stations.

Inspection of the data indicates a negative calibration bias prior to 1 November, which changed to a positive bias after that date.

2. The REM Scientific Company ozone analyzer showed an average slope of 1.0153, with a SD of .1569. The average slope is somewhat better than that of the RAMS sensors, however the SD is greater.

3. The Meloy Total Sulfur recorders gave an average slope of .9230 with a SD of .2168. This is comparable to the performance of the RAMS Meloys.

4. The carbon monoxide analyzers gave an average slope of .9255, with a SD of .0379.

Helicopter audits were conducted pre-flight and post-flight in an effort to quantify the degree to which instrument drift may have occurred as a result of the rigors of flight. The agreement between pre-flight and post-flight audits was generally good with the exception of the ozone analyzers.

St. Louis City and County Stations use a wide variety of instruments, as indicated on the summary tables. The data were, nevertheless, summarized for each pollutant, since any future intercomparison of data will probably not take instrument types into account.

A number of the City and County sites employ relatively old analyzers of the wet chemical variety with such long response times that multipoint audits could not be conducted within a reasonable period of time.

Data for NO indicate a large negative error (average slope of 0.4330), with a large standard deviation (.3047). Data for $NO_2$, taken only at 2 stations, appear to be unrelated to actual concentrations. Ozone data show an average slope of 1.0867; however, the large standard deviation of .4099 is an indication of the large spread of actual values. Values for total sulfur indicate an average slope of .9294, but the standard deviation is again large (.3586).

The carbon monoxide analyzers gave an average slope of 1.1288 with a rather large SD of .1599.

The total hydrocarbon analyzers gave an average slope of .7904 with a SD of .1993.

Thus, the audit results indicate that data from these sources are subject to large error and should be used with caution.

Two Illinois State EPA stations were audited. These stations have Dasibi ozone analyzers, which gave a slope of .9902, with a standard deviation of .0144. The $SO_2$ values obtained by Technicon IV analyzers yielded a correlation of .9556 with a standard deviation of .0649.

Miscellaneous audits included the audits of instruments used on the DaVinci balloon, and various aircraft and vans used by expeditionary groups. The results, shown in Table 6, indicate slopes ranging from .460 to 1.2650.

During the course of all audit work, a wide variety of analyzers, support equipment, and monitoring configurations were encountered. Additionally, the analyzers used for aerial studies were not always audited in place in the aircraft. In a number of instances, ambient temperatures differed significantly from normal room temperature. In all cases the responsible investigator was consulted prior to the audit in regard to instrument specifications relevant to the audit and to insure that the introduction of audit gas would simulate the introduction of the monitored pollutant during normal operation. When the introduction of audit gas through normal sampling lines was not possible, as in the case where high by-pass flows existed in sample lines, audit gases were introduced through auxillary ports specifically designed for calibration.

# 4.0 FILTER STUDY

The primary purpose of this part of the task was to conduct a study of the effect of particulate filters on measurements by RAMS analyzers. The pollutants of concern were sulfur dioxide ($SO_2$), nitric oxide (NO) and ozone ($O_3$).

## 4.1 EXPERIMENTAL

A study was made of the effects of new and used Teflon particulate filters placed in the inlet of instruments measuring atmospheric pollutants. The filters were 47 mm in diameter with an average pore size of 10 microns. Both dry air and humidified air were used as diluent. Gases studied were $SO_2$, NO, $O_3$, $NO_2 + O_3$, $SO_2 + O_3$. NO was obtained by diluting the contents of an NO in nitrogen compressed gas cylinder. Ozone was obtained from a constant-current ozone generator. $NO_2$ was obtained by the gas phase titration of NO with ozone. $SO_2$ was obtained from an NBS permeation tube. Equipment was set up in such a fashion as to allow rapid change from one filter to another and from dry air to wet air (Figure 14). The flow diagram shows airflow from the cylinder to the Bendix calibrator, either directly or through a water bubbler. Output from the calibrator entered a glass manifold for distribution. Manifold air was sampled by an EG&G dew point hygrometer, the output of which was monitored by a Leeds and Northrup recorder. The dew point hygrometer was checked by deriving relative humidity from outdoor dew point and temperature measurements and comparison to relative humidity measurements taken with a sling psychrometer. Crosschecks were also made with relative humidity measurements from the National Weather Service. In no case was a difference greater than 5% noted.

The second line from the glass manifold led to a series of valves and filters so that the gas stream could be shifted from one filter to another (or none) without interruption or without opening the circuit. The filters were replaced during the changeover from wet to dry diluent air and again

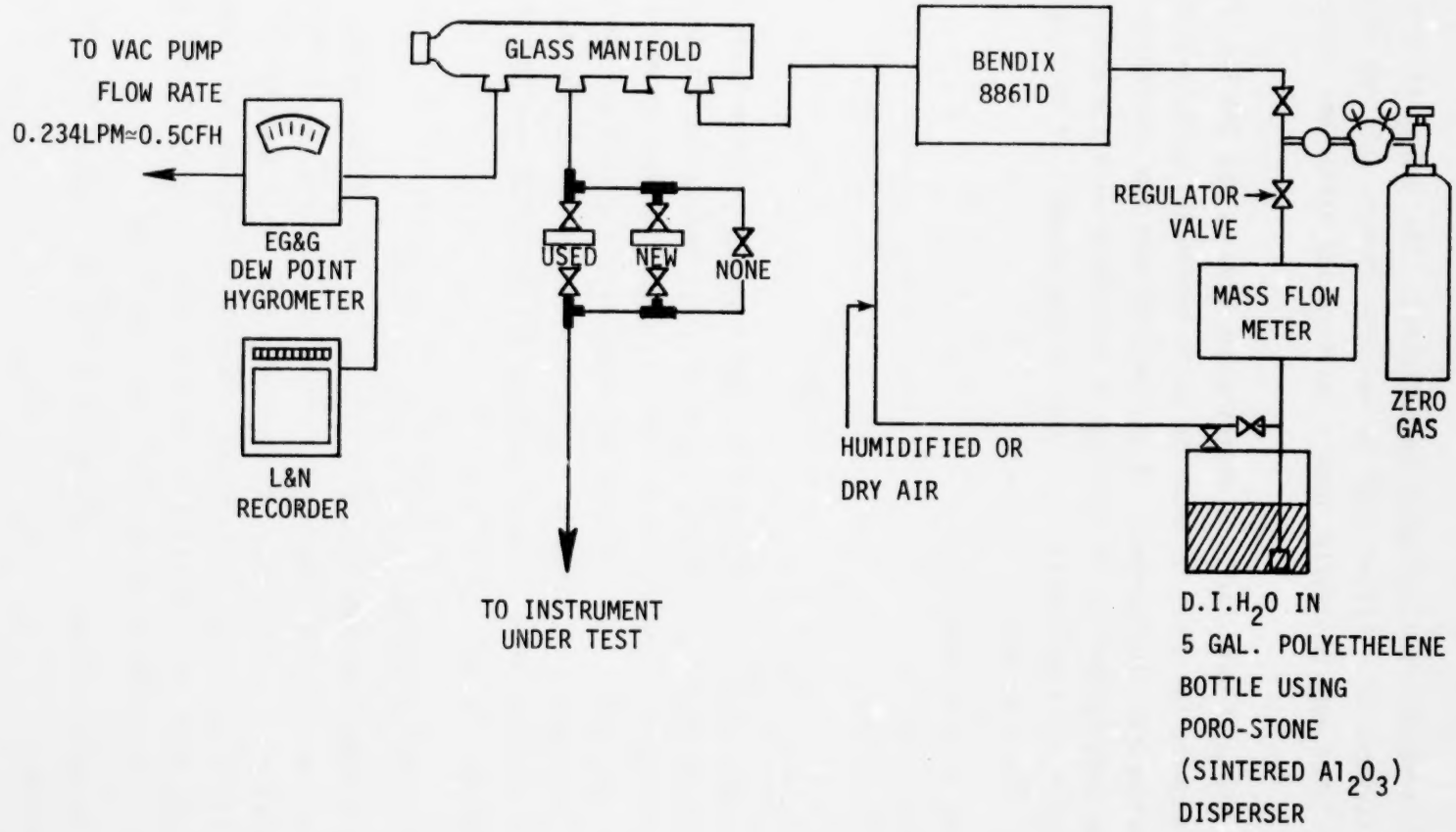



FIGURE 14. SCHEMATIC LAYOUT FOR FILTER STUDY

during the changeover from pollutant to pollutant. The "used" filters were taken from station 120. Filter 'age' varied from five to thirteen days. All filters taken were obviously "used": particulate matter was visible on all.

Before the work was started a decision was made by the EPA Task Coordinator to randomize the order of tests so as to remove any systematic bias as the tests proceeded. Furthermore, it was decided that two replicates were required per test condition. Proceeding in accordance with the above directive the first randomization was made in the sequence of testing the pollutants. The order was as follows:

1. $SO_2$ (Tracor and Meloy)
2. $NO_2 + O_3$
3. NO
4. $O_3$
5. $SO_2 + O_3$

The random sequence established for the individual filter tests is obvious from the tables of results (Tables 8-13). Nearly every test involving a different pollutant and/or humidity condition was preceeded by a run using zero gas. When the test was completed, the zero gas run was repeated. Concentrations of pollutants observed represent an average of at least 12 readings made 4 minutes apart after the system was judged to have reached equilibrium.

## 4.2 RESULTS AND DISCUSSION

Table 7 summarizes the results of the particulate filter study. In comparing wet and dry air results, it should be noted that no correction for the volume added by water vapor has been included. This amounts to 1-1.5% at the relative humidities encountered. Reproducibility of duplicate runs was generally good, with standard deviations within a range of .001 to .008 ppm. Thus, changes of the order of 5% are significant.

The following conclusions can be drawn from the results for the pollutants tested:

TABLE 7. SUMMARY OF RESULTS FOR PARTICULATE FILTER STUDY

DRY GAS

(values in ppm)

| | | | | | $SO_2 + O_3$ | | |
|---|---|---|---|---|---|---|---|
| POLLUTANT INSTRUMENT | NO Mon. Lab Δ | $NO_2$ Monitor Δ | $O_3$ Monitor Δ | $SO_2$ Tracor Δ | $SO_2$ Tracor Δ | $O_3$ Monitor Δ | $SO_2$ Meloy Δ |
| Relative Humidity % | 5.5 | 5.5 | 7.4 | 8.1 | 7.6 | 7.6 | 7.3 |
| New Filter | .155 | .161 | .124 | .081 | .242 | .160 | .158 |
| | .001 | -.001 | -.036 | -.005 | -.009 | -.021 | +.002 |
| No Filter | .154 | .162 | .160 | .086 | .251 | .181 | .156 |
| | .002 | .000 | -.012 | -.001 | -.000 | -.009 | +.003 |
| Used Filter | .156 | .162 | .148 | .085 | .251 | .172 | .159 |
| WET GAS | | | | | | | |
| Relative Humidity % | 51 | 40.5 | 64. | 71. | 64 | 64 | 61 |
| New Filter | .135 | .156 | .135 | .070 | .231 | .157 | .173 |
| | -.003 | -.007 | -.040 | -.002 | -.010 | -.021 | +.002 |
| No Filter | .138 | .163 | .175 | .072 | .241 | .178 | .171 |
| | -.003 | -.000 | -.016 | -.001 | -.000 | -.008 | -.001 |
| Used Filter | .135 | .163 | .159 | .071 | .241 | .172 | .170 |

Nitric Oxide (NO)

An increase of relative humidity from 5 to 50% results in about 10% attenuation of the response of the NO analyzer. The presence of a particulate filter appears to have no effect.

Nitrogen Dioxide ($NO_2$)

Moist air appears to have no effect on the $NO_2$ reading obtained from mixtures of $NO_2 + O_3$. A new particulate filter caused a 4% drop in the $NO_2$ reading for moist air, but had no effect on the $NO_2$ reading for dry air.

Ozone ($O_3$)

Moist air enhanced the response of the instrument to ozone by 10%. A fresh particulate filter resulted in a 23% decrease in ozone level. A used filter had a lesser effect (approximately 8%). Analyzer response time was significant. As a result, some compromise in data quality occurred yielding apparent inconsistencies such as two significantly different observations taken on the same filter tested twice in succession.

Sulfur Dioxide ($SO_2$) - Tracor Analyzer

Moist air resulted in a significant signal attenuation (16%). The introduction of a particulate filter did not affect the $SO_2$ level significantly.

Sulfur Dioxide - Ozone Mixtures

This mixture contained a much higher $SO_2$ concentration than the one discussed above (.252 ppm vs. .085 ppm). However, the attenuation in $SO_2$ measurement due to the presence of moisture was about the same (0.01 ppm). The particulate filter produced no significant change in the $SO_2$ measurement.

No change in ozone level resulted from the use of moist air. A new particulate filter resulted in a 12% reduction of ozone level, which dropped to 5% when a used filter was introduced.

Sulfur Dioxide ($SO_2$) - Meloy Analyzer

This instrument showed an enhanced response to the introduction of moist air (11%); as before, the introduction of a particulate filter did not result

in significant changes.

The results indicate:

1. Moist air alters the instrument response to NO, $O_3$ and $SO_2$. This effect can be alleviated by calibrating the instruments with air of about the same relative humidity as that which will be sampled.

2. Particulate filters, especially fresh ones, have a pronounced attenuating effect on the ozone level. This effect decreases as the filter becomes conditioned, but remains significant (5-10%).

3. None of the analyzers employed in this testing were sensitive to zero air humidity, with or without a filter.

Data for individual tests are shown in Tables 8-13 and Figures 15-21.

TABLE 8. DATA SUMMARY, NO POLLUTANT
MONITOR LABS INSTRUMENT

| | | Conc. PPM |
|---|---|---|
| I. | Wet air, 51% R.H., R.T. 70°F, NO | |
| | A. Zero Gas | |
| | 1. No filter | .005 |
| | 2. New filter | .005 |
| | 3. Used filter | .005 |
| | B. Used filter, NO | .135 |
| | C. New filter, NO | .135 |
| | D. Used filter, NO | .135 |
| | E. New filter, NO | .135 |
| | F. No filter, NO | .138 |
| | G. No filter, NO | .138 |
| | H. Zero gas | |
| | 1. No filter | .003 |
| | 2. New filter | .002 |
| | 3. Used filter | .002 |
| II. | Dry air, 5.5% R.H., R.T. 70°F, NO | Conc. PPM |
| | A. Zero gas | |
| | 1. No filter | .001 |
| | 2. New filter | .001 |
| | 3. Used filter | .001 |
| | B. No filter, NO | .152 |
| | C. New filter, NO | .153 |
| | D. Used filter, NO | .155 |
| | E. Used filter, NO | .156 |
| | F. New filter, NO | .156 |
| | G. No filter, NO | .156 |
| | H. Zero gas | |
| | 1. No filter | .002 |
| | 2. New filter | .002 |
| | 3. Used filter | .003 |

Reproduced from
best available copy.

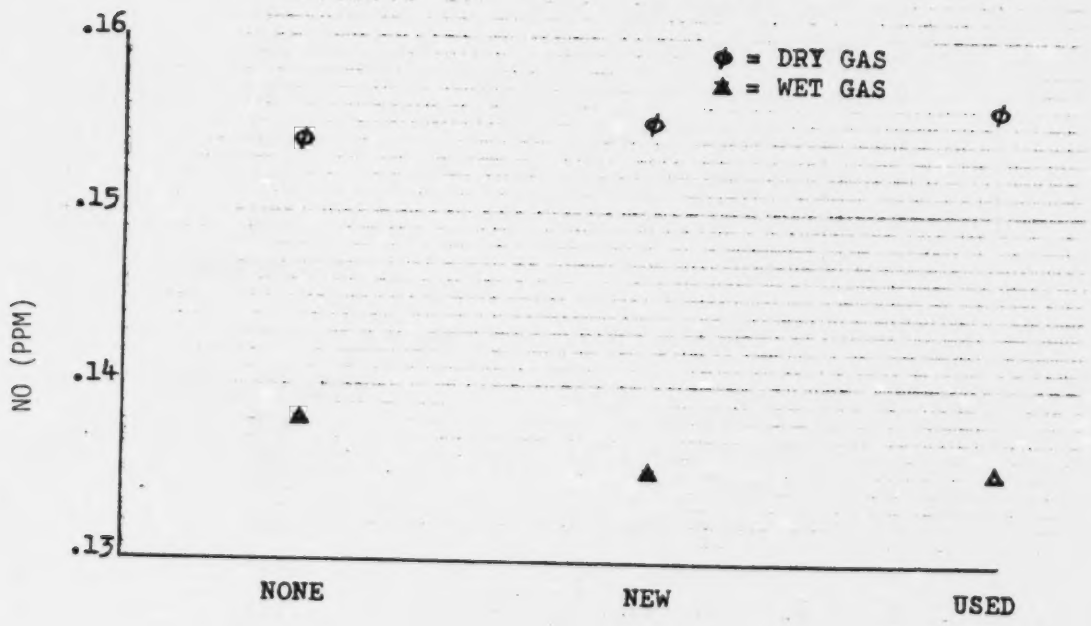



FIGURE 15. NO POLLUTANT

TABLE 9. DATA SUMMARY, $NO_2$ + OZONE POLLUTANT MONITOR LABS INSTRUMENT

| | | Conc. $NO_2$, PPM |
|---|---|---|
| I. | Wet air, 40.5% R.H., R.T. 70°F, $NO_2 + O_3$ | |
| A. | Zero Gas | |
| | 1. No filter | .005 |
| | 2. New filter | .004 |
| | 3. Used filter | .006 |
| B. | Used filter, $NO_2 + O_3$ | .161 |
| C. | New Filter, $NO_2 + O_3$ | .155 |
| D. | No filter, $NO_2 + O_3$ | .162 |
| E. | No filter, $NO_2 + O_3$ | .164 |
| F. | New filter, $NO_2 + O_3$ | .156 |
| G. | Used filter, $NO_2 + O_3$ | .165 |
| H. | Zero gas | not repeated |
| II. | Dry air, 5.5% R.H., R.T. 70°F, $NO_2 + O_3$ | |
| A. | Zero Gas | |
| | 1. No filter | .002 |
| | 2. New filter | .002 |
| | 3. Used filter | .003 |
| B. | Used filter, $NO_2 + O_3$ | .161 |
| C. | No filter, $NO_2 + O_3$ | .161 |
| D. | Used filter, $NO_2 + O_3$ | .162 |
| E. | No filter, $NO_2 + O_3$ | .163 |
| F. | New filter, $NO_2 + O_3$ | .160 |
| G. | New filter, $NO_2 + O_3$ | .162 |
| H. | Zero gas | not repeated |

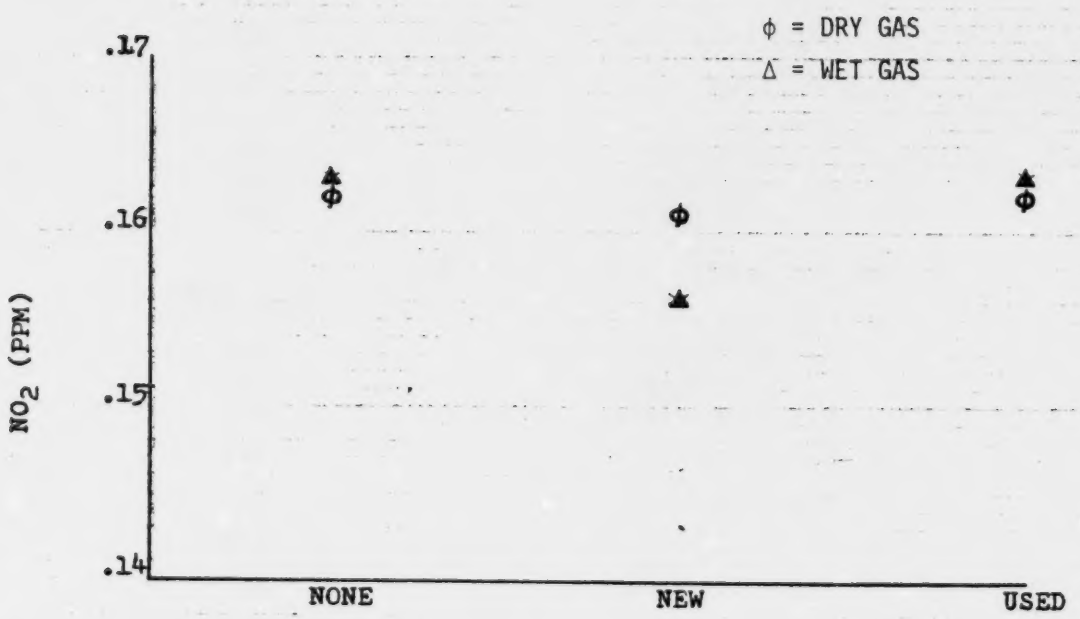



FIGURE 16. $NO_2 + O_3$ POLLUTANT

TABLE 10. DATA SUMMARY, OZONE POLLUTANT MONITOR LABS INSTRUMENT*

| | | Conc. PPM |
|---|---|---|
| I. | Dry air, 7.4% R.H., R.T. 70°F, $O_3$ | |
| | A. Zero gas | |
| | 1. No filter | .005 |
| | 2. New filter | .005 |
| | 3. Used filter | .005 |
| | B. No filter, $O_3$ | .157 |
| | C. New filter, $O_3$ | .120 |
| | D. New filter, $O_3$ | .128 |
| | E. Used filter, $O_3$ | .144 |
| | F. Used filter, $O_3$ | .151 |
| | G. No filter, $O_3$ | .163 |
| | H. Zero gas | |
| | 1. No filter | .005 |
| | 2. New filter | .006 |
| | 3. Used filter | .006 |
| II. | Wet air, 64% R.H., R.T. 70°F, $O_3$ | |
| | | Conc. PPM |
| | A. Zero gas | |
| | 1. No filter | .005 |
| | 2. New filter | .005 |
| | 3. Used filter | .005 |
| | B. New filter, $O_3$ | .133 |
| | C. New filter, $O_3$ | .137 |
| | D. No filter, $O_3$ | .170 |
| | E. Used filter, $O_3$ | .157 |
| | F. Used filter, $O_3$ | .161 |
| | G. No filter, $O_3$ | .180 |
| | H. Zero gas | |
| | 1. No filter | .004 |
| | 2. New filter | .005 |
| | 3. Used filter | .004 |

* Bendix ozone monitor in Winnebago exchanged for M.L. Extreme instrument drift on Bendix.

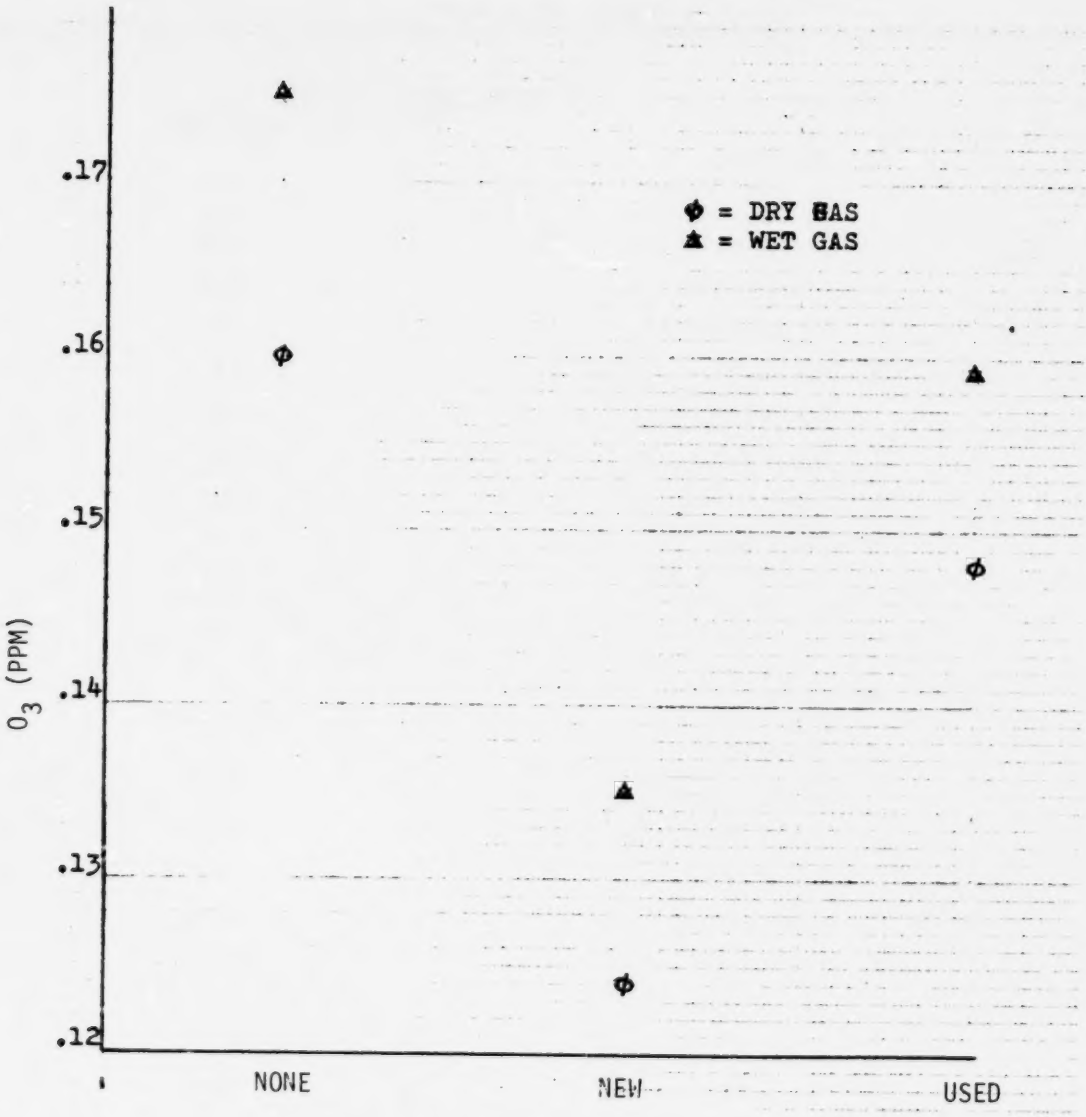



FIGURE 17. OZONE POLLUTANT

TABLE 11. DATA SUMMARY, $SO_2$ POLLUTANT
TRACOR INSTRUMENT

| | | Conc. PPM |
|---|---|---|
| I. | Dry air, 8.1% R.H., R.T 70°F, $SO_2$ | |
| A. | Zero Gas | |
| 1. | No filter | .000 |
| 2. | New filter | .000 |
| 3. | Used filter | .000 |
| B. | Used filter, $SO_2$ | .087 |
| C. | No filter, $SO_2$ | .087 |
| D. | New filter, $SO_2$ | .081 |
| E. | No filter, $SO_2$ | .084 |
| F. | New filter, $SO_2$ | .081 |
| G. | Used filter, $SO_2$ | .082 |
| H. | Zero gas | |
| 1. | No filter | .000 |
| 2. | New filter | .000 |
| 3. | Used filter | .000 |

| | | Conc. PPM |
|---|---|---|
| II. | Wet air, 71% R.H., R.T. 63°F, $SO_2$ | |
| A. | Zero Gas | |
| 1. | No filter | .000 |
| 2. | New filter | .000 |
| 3. | Used filter | .000 |
| B. | New filter, $SO_2$ | .070 |
| C. | New filter, $SO_2$ | .070 |
| D. | No filter, $SO_2$ | .072 |
| E. | No filter, $SO_2$ | .072 |
| F. | Used filter, $SO_2$ | .071 |
| G. | Used filter, $SO_2$ | .071 |
| H. | Zero gas | |
| 1. | No filter | .000 |
| 2. | New filter | .000 |
| 3. | Used filter | .000 |

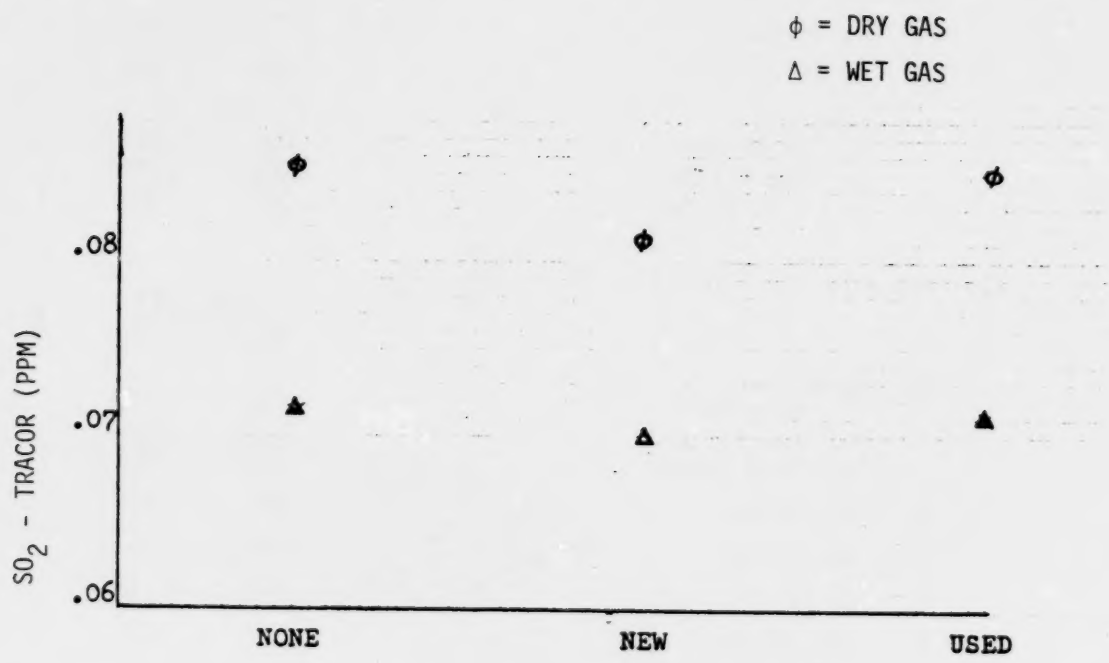



FIGURE 18. $SO_2$ POLLUTANT (TRACOR)

TABLE 12. DATA SUMMARY, SULFUR DIOXIDE PLUS OZONE POLLUTANT
TRACOR AND MONITOR LABS INSTRUMENTS

| | | Conc. PPM | |
|---|---|---|---|
| | | $SO_2$ | $O_3$ |
| I. | Dry air, 7.6% R.H., R.T. 70°F, $SO_2 + O_3$ | | |
| A. | Zero gas | | |
| | 1. No filter | .002 | .004 |
| | 2. New filter | .002 | .004 |
| | 3. Used filter | .002 | .004 |
| B. | Used filter | .251 | .168 |
| C. | Used filter | .251 | .176 |
| D. | New filter | .242 | .159 |
| E. | New filter | .242 | .161 |
| F. | No filter | .251 | .180 |
| G. | No filter | .251 | .182 |
| H. | Zero gas | | |
| | 1. No filter | .002 | .006 |
| | 2. New filter | .002 | .006 |
| | 3. Used filter | .002 | .006 |
| II. | Wet air, 64% R.H., R.T. 70°F, $SO_2 + O_3$ | | |
| | | Conc. PPM | |
| | | $SO_2$ | $O_3$ |
| A. | Zero gas | | |
| | 1. No filter | .002 | .005 |
| | 2. New filter | .002 | .005 |
| | 3. Used filter | .002 | .005 |
| B. | No filter | .241 | .178 |
| C. | New filter | .231 | .156 |
| D. | No filter | .241 | .178 |
| E. | New filter | .231 | .157 |
| F. | Used filter | .241 | .171 |
| G. | Used filter | .241 | .172 |
| H. | Zero gas | | |
| | 1. No filter | .002 | .004 |
| | 2. New filter | .002 | .003 |
| | 3. Used filter | .002 | .004 |

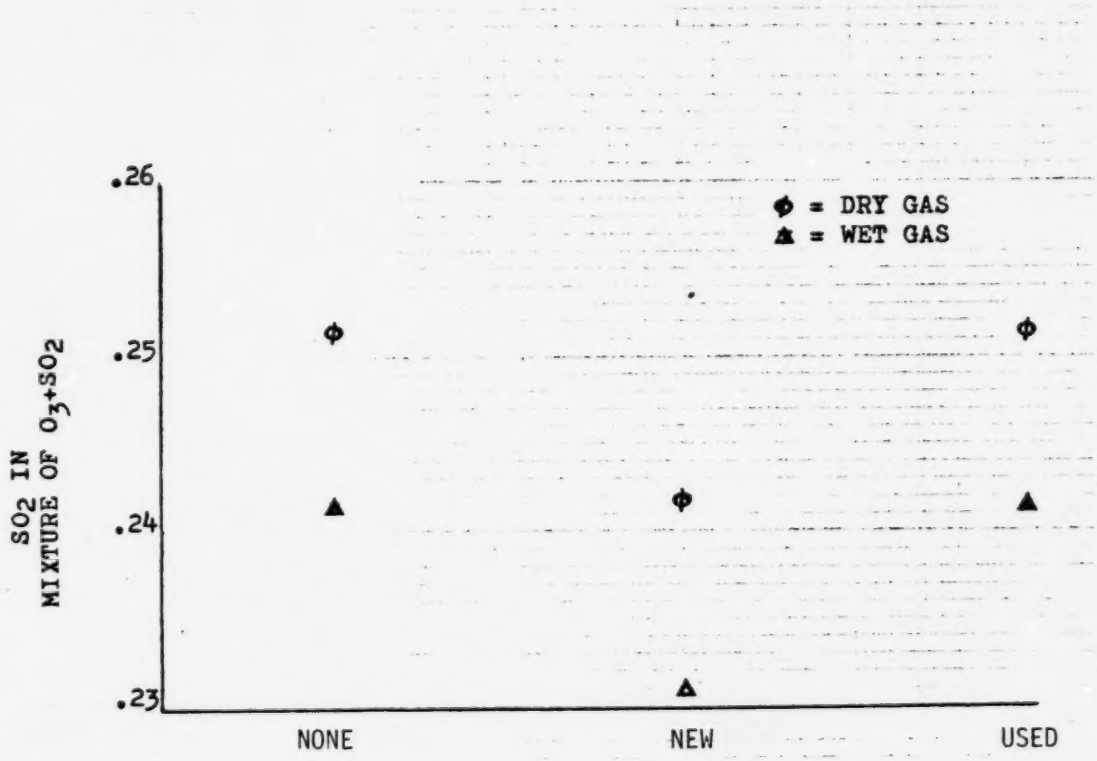



FIGURE 19. $SO_2$ + $O_3$ POLLUTANT, $SO_2$

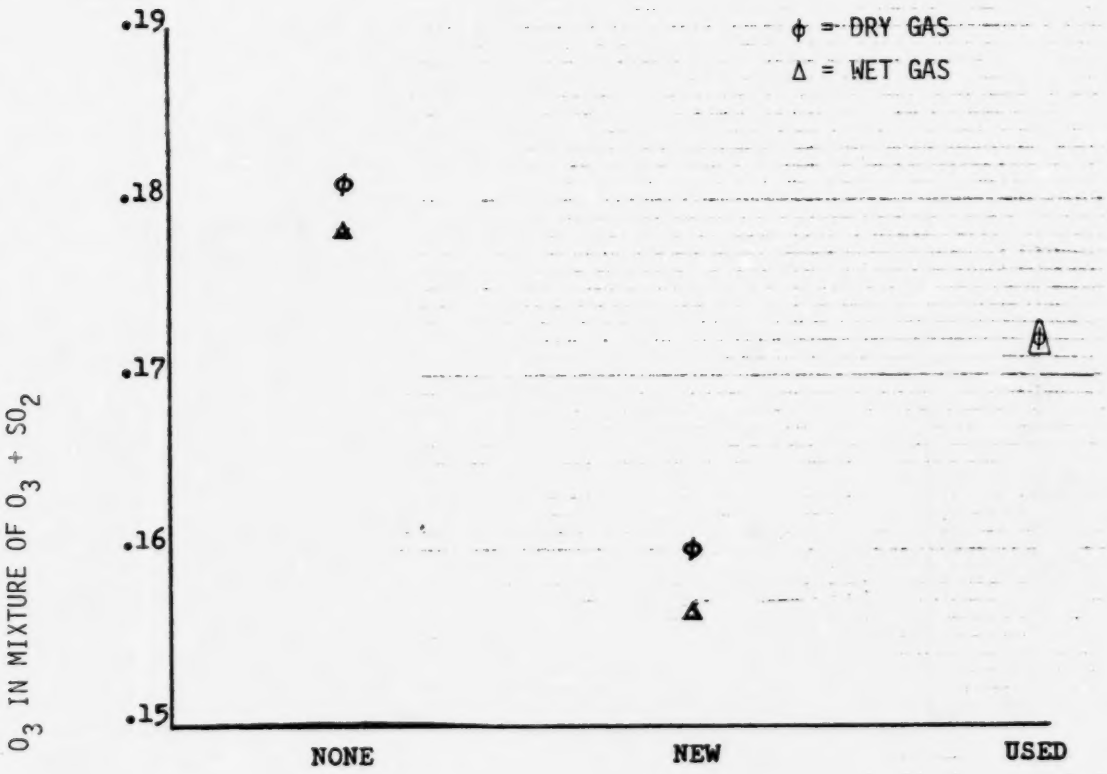



FIGURE 20. $SO_2$ + $O_3$ POLLUTANT, $O_3$

TABLE 13. DATA SUMMARY, $SO_2$ POLLUTANT
MELOY* INSTRUMENT

| | | Conc. PPM |
|---|---|---|
| I. | Dry air, 7.3% R.H., R.T. 67°F, $SO_2$ | |
| | A. Zero Gas | |
| | 1. No filter | -.008 |
| | 2. New filter | -.008 |
| | 3. Used filter | -.008 |
| | B. Used filter, $SO_2$ | .154 |
| | C. No filter, $SO_2$ | .151 |
| | D. New filter, $SO_2$ | .155 |
| | E. No filter, $SO_2$ | .160 |
| | F. New filter, $SO_2$ | .160 |
| | G. Used filter, $SO_2$ | .163 |
| | H. Zero gas | |
| | 1. No filter | -.009 |
| | 2. New filter | -.018 |
| | 3. Used filter | -.016 |
| II. | Wet air, 61% R.H., R.T. 67°F, $SO_2$ | Conc. PPM |
| | A. Zero Gas | |
| | 1. No filter | -.004 |
| | 2. New filter | -.007 |
| | 3. Used filter | -.006 |
| | B. Used filter, $SO_2$ | .167 |
| | C. No filter, $SO_2$ | .169 |
| | D. New filter, $SO_2$ | .173 |
| | E. No filter, $SO_2$ | .173 |
| | F. New filter, $SO_2$ | .172 |
| | G. Used filter, $SO_2$ | .173 |
| | H. Zero gas | |
| | 1. No filter | -.008 |
| | 2. New filter | -.018 |
| | 3. Used filter | -.018 |

*Meloy analyzer at RAMS station 102 was used to collect $SO_2$ data. This test was not run until all of the other tests were completed.

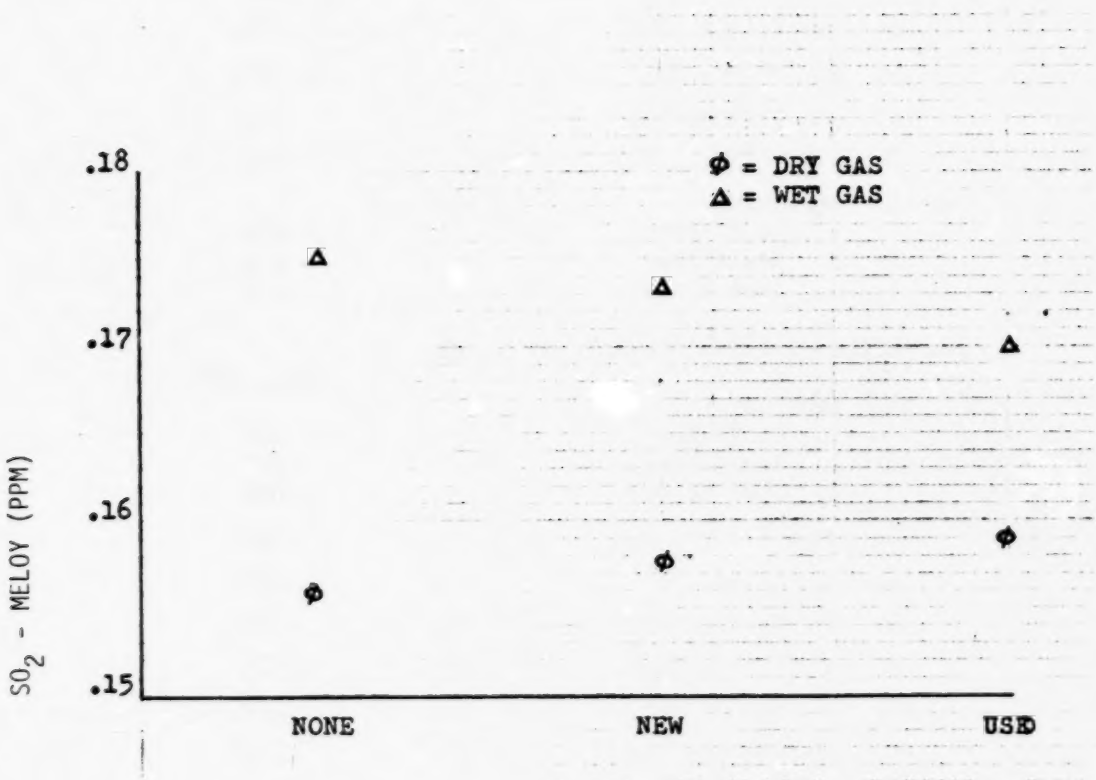



FIGURE 21. $SO_2$ POLLUTANT (MELOY)

## 5.0 CALIBRATOR OPERATING VARIABLES; AN $SO_2$ STUDY

This work is an extension of Task Order 106 using the modified Bendix 8861 portable calibration system and National Bureau of Standards $SO_2$ permeation tubes in a study of the effect of several variables on the accuracy of prepared $SO_2$ calibration gas mixtures. Variables investigated include flow rate over the permeation tube, tube length, attitude of the permeation tube chamber, and ambient temperature during the use of the 8861 calibration system.

### 5.1 EQUIPMENT

The following equipment was used during this phase of the Task Order:

1. A Bendix portable calibrator (described in Section 3.4)
2. A Meloy $SO_2$ analyzer
3. An environmental chamber

The equipment employed during the first phase of testing was configured as outlined in Figure 22. Scrubbed ambient air was used during all tests. Scrubbing consisted of passage through Drierite, activated charcoal, and Ascarite. Ascarite scrubbing of carbon dioxide proved necessary in order to eliminate the variable suppression of $SO_2$ analyzer response due to changing $CO_2$ levels in the diluent air. Tests were performed to verify that $CO_2$ removal was complete by comparing the span response of the Meloy $SO_2$ analyzer with bottled zero air as diluent to the span response with ascarite scrubbed air as diluent.

The equipment configuration during the second phase of testing is displayed in Figure 23. An environmental chamber was constructed using a wooden framework and cardboard sheeting to enclose the Bendix portable calibration system. Components contained within the environmental chamber are shown as being within a dotted line in Figure 23.

The Meloy $SO_2$ analyzer was calibrated prior to testing following

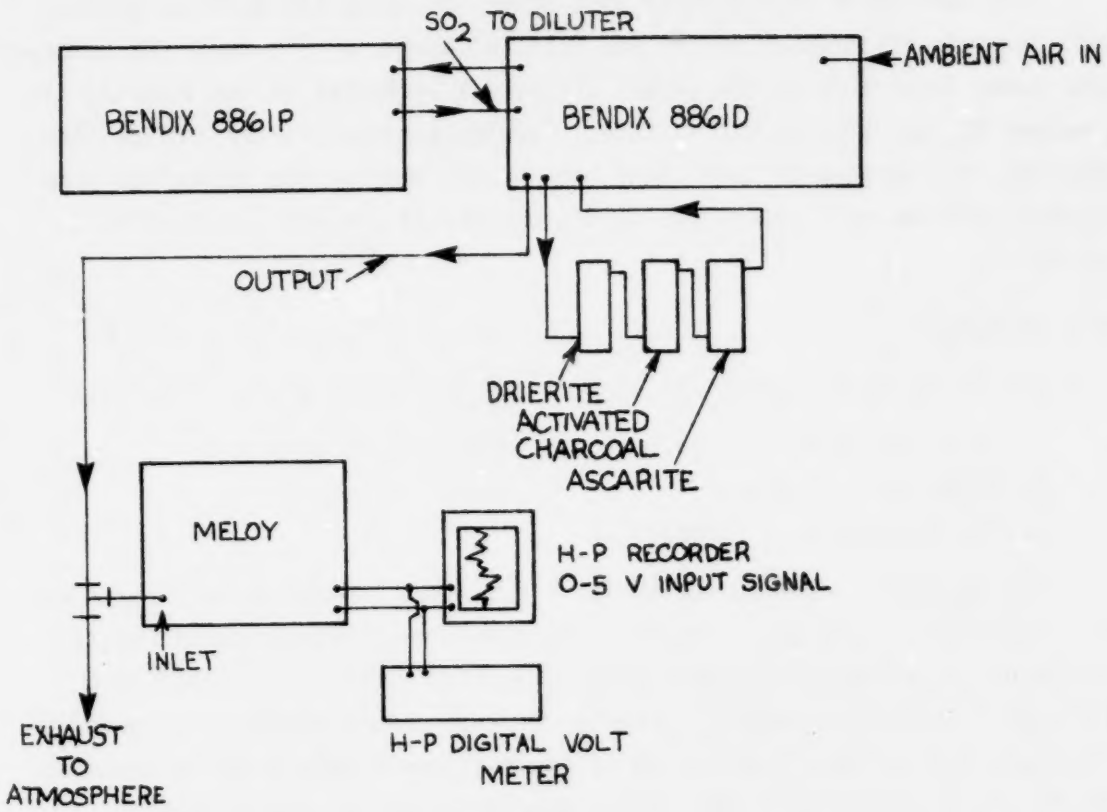



FIGURE 22. INITIAL EQUIPMENT CONFIGURATION FOR $SO_2$ STUDY

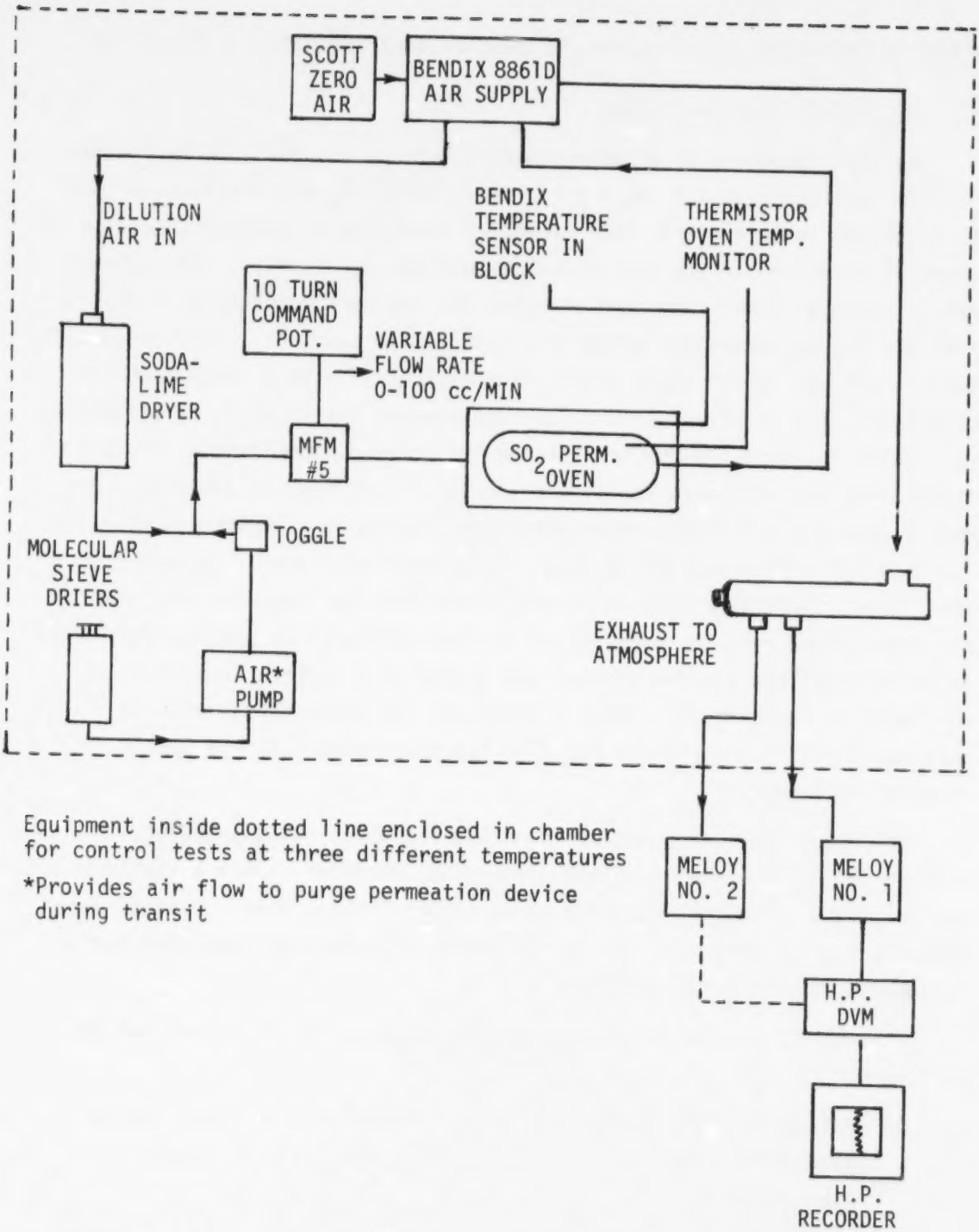



FIGURE 23. FINAL EQUIPMENT CONFIGURATION FOR $SO_2$ STUDY

standard procedures yielding the calibration data presented in Figure 24.

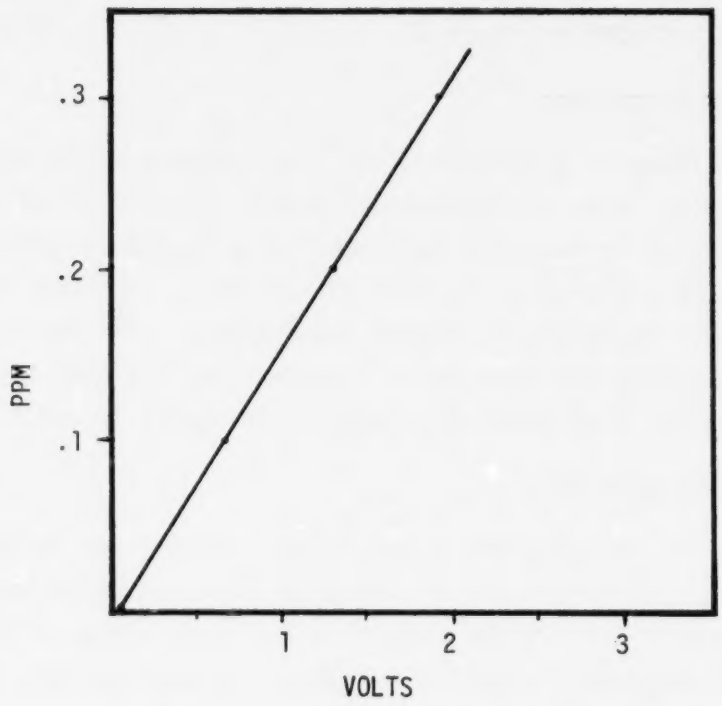
## 5.2 PERMEATION TUBE VARIABLES

An $SO_2$ concentration of approximately 0.3 ppm was selected for testing. At this concentration a 2 cm, a 5 cm, and a 10 cm $SO_2$ permeation tube could be exchanged in turn within the permeation tube chamber without exceeding the range of dilution airflow measurement within the Bendix 8861. The appropriate dilution airflow rates were selected for the particular tube in use so that the $SO_2$ concentration prepared should remain constant. Airflow over the tube in use was varied using a mass flow controller with a range of 0-100 cc/minute. The effect of permeation tube chamber position was determined by physically rotating the chamber through 90° between experiments. Chamber temperature was monitored during the course of the study in two ways. The Bendix platinum resistance thermometer embedded in the aluminum block surrounding the Teflon permeation tube cylinder was monitored. In addition, a small glass thermistor was placed within the tube cylinder and the actual air temperature over the permeation tube was monitored by placing the thermistor in a voltage divider circuit and recording a voltage inversely proportional to temperature. Thus, a change in air temperature could be measured directly and without the time lag associated with the Bendix temperature sensor.

The Meloy analyzer output voltage was monitored using a Hewlett-Packard DVM and a Hewlett-Packard strip chart recorder. Once a stable trace was obtained, readings were taken at 15 minute intervals and voltages were converted to concentrations using the slope and intercept developed during calibration of the Meloy analyzer.

Throughout this phase of testing, the sequence of operations was as follows:

1. Permeation tube chamber placed in a horizontal position, purge flow rate stabilized (5 cc/min., 10 cc/min., etc.), chamber temperature at 30.0°C.
2. Recorder trace stable, analyzer signal level and chamber temperature recorded.




| Conc. $SO_2$, ppm | Meloy Output, Volts |
|---|---|
| 0.00 | 0.064 |
| 0.10 | 0.664 |
| 0.20 | 1.280 |
| 0.30 | 1.905 |

FIGURE 24. MELOY $SO_2$ ANALYZER CALIBRATION

3. Chamber placed in a vertical position. Step 2 repeated.

4. Chamber returned to a horizontal position.

The results obtained are presented in Tables 14 and 15. A typical strip chart record is included as Figure 25.

## 5.3 TEMPERATURE EXCURSIONS

The second phase of testing involved the placement of the Bendix 8861 portable calibrator in an environmental chamber. Cooling of the system components was achieved by exposing the chamber to a stream of outside air at 10°C. Heating was achieved by use of a strip heater. A blower and a damper were employed for regulation of chamber temperature. This test was performed with a 2 cm $SO_2$ permeation tube and at a purge flow rate over the tube of 5 cc/min. The results obtained are presented in Tables 16 and 17.

## 5.4 RESULTS AND DISCUSSION

A small effect was observed as the purge flow rate was varied over the 2 cm and the 5 cm permeation tubes. The data indicates an increase in analyzer response of 1-2% as the purge flow rate was increased from 5 cc/minute to 50 cc/minute. Analyzer response remained constant at purge flow rates above 50 cc/minute regardless of tube length.

The effect of varying the permeation chamber position was to create an abrupt transitory disturbance within the chamber with a resulting change in $SO_2$ concentration observed at the analyzer. The magnitude of the transitory change in concentration ranged from 10-25% and appeared to depend on the position of the tube within the chamber prior to the tilt. The disturbance in the $SO_2$ concentration persisted for about 15-20 minutes with a 5 cc/minute purge flow rate and for about 1 minute with a 100 cc/minute purge flow rate. The equilibrium $SO_2$ concentration remained constant regardless of the chamber position as the data in Table 14 indicates. Thus, the reservoiring of $SO_2$ within the chamber would not appear to be a significant source of error even at a purge flow rate of 5 cc/minute.

The data obtained in regard to tube length are anomalous. Analyzer response increased 5% after the exhange of a 5 cm tube for a 2 cm tube. A 4%

TABLE 14. EFFECT OF PERMEATION CHAMBER FLOW RATE ON SIGNAL RESPONSE

A. 2.0 cm permeation tube

| FLOW CC/MIN | OVEN POSITION | $SO_2$ OBSERVED, PPM | OVEN TEMPERATURE THERMISTOR(V) | | BENDIX °C |
|---|---|---|---|---|---|
| 5.0 | horizontal | .306 | .549 | (30.00°C) | 30.00 |
| | vertical | .310 | .549 | (30.00°C | 30.00 |
| | horizontal | .312 | .549 | (30.00°C) | 30.00 |
| 10.0 | horizontal | .314 | .549 | (30.00°C) | 30.00 |
| | vertical | .314 | .549 | (30.00°C) | 30.00 |
| | horizontal | .314 | .549 | (30.00°C) | 30.00 |
| 25.0 | horizontal | .317 | .549 | (30.00°C) | 30.00 |
| | vertical | .317 | .549 | (30.00°C) | 30.00 |
| | horizontal | .317 | .549 | (30.00°C) | 30.00 |
| 50.0 | horizontal | .320 | .549 | (30.00°C) | 30.00 |
| | vertical | .320 | .549 | (30.00°C) | 30.00 |
| | horizontal | .319 | .549 | (30.00°C) | 30.00 |
| 100.0 | horizontal | .320 | .549 | (30.00°C) | 30.00 |
| | vertical | .320 | .549 | (30.00°C) | 30.00 |
| | horizontal | .320 | .549 | (30.00°C) | 30.00 |

B. 5.0 cm permeation tube

| | | | | | |
|---|---|---|---|---|---|
| 5.0 | horizontal | .330 | .551 | (29.92°C) | 30.01 |
| | vertical | .330 | .551 | (29.92°C) | 30.01 |
| | horizontal | .328 | .551 | (29.92°C) | 30.01 |
| 10.0 | horizontal | .328 | .550 | (29.96°C) | 30.00 |
| | vertical | .330 | .550 | (29.96°C) | 30.00 |
| | horizontal | .333 | .550 | (29.96°C) | 30.00 |
| 25.0 | horizontal | .339 | .550 | (29.96°C) | 30.00 |
| | vertical | .338 | .550 | (29.96°C) | 30.00 |
| | horizontal | .336 | .550 | (29.96°C) | 30.00 |
| 50.0 | horizontal | .335 | .550 | (29.96°C) | 30.00 |
| | vertical | .335 | .550 | (29.96°C) | 30.00 |
| | horizontal | .335 | .550 | (29.96°C) | 30.00 |
| 100.0 | horizontal | .327 | .550 | (29.96°C) | 30.00 |
| | vertical | .335 | .550 | (29.96°C) | 30.00 |
| | horizontal | .335 | .550 | (29.96°C) | 30.00 |
| recheck 5.0 | horizontal | .328 | | | |

(continued)

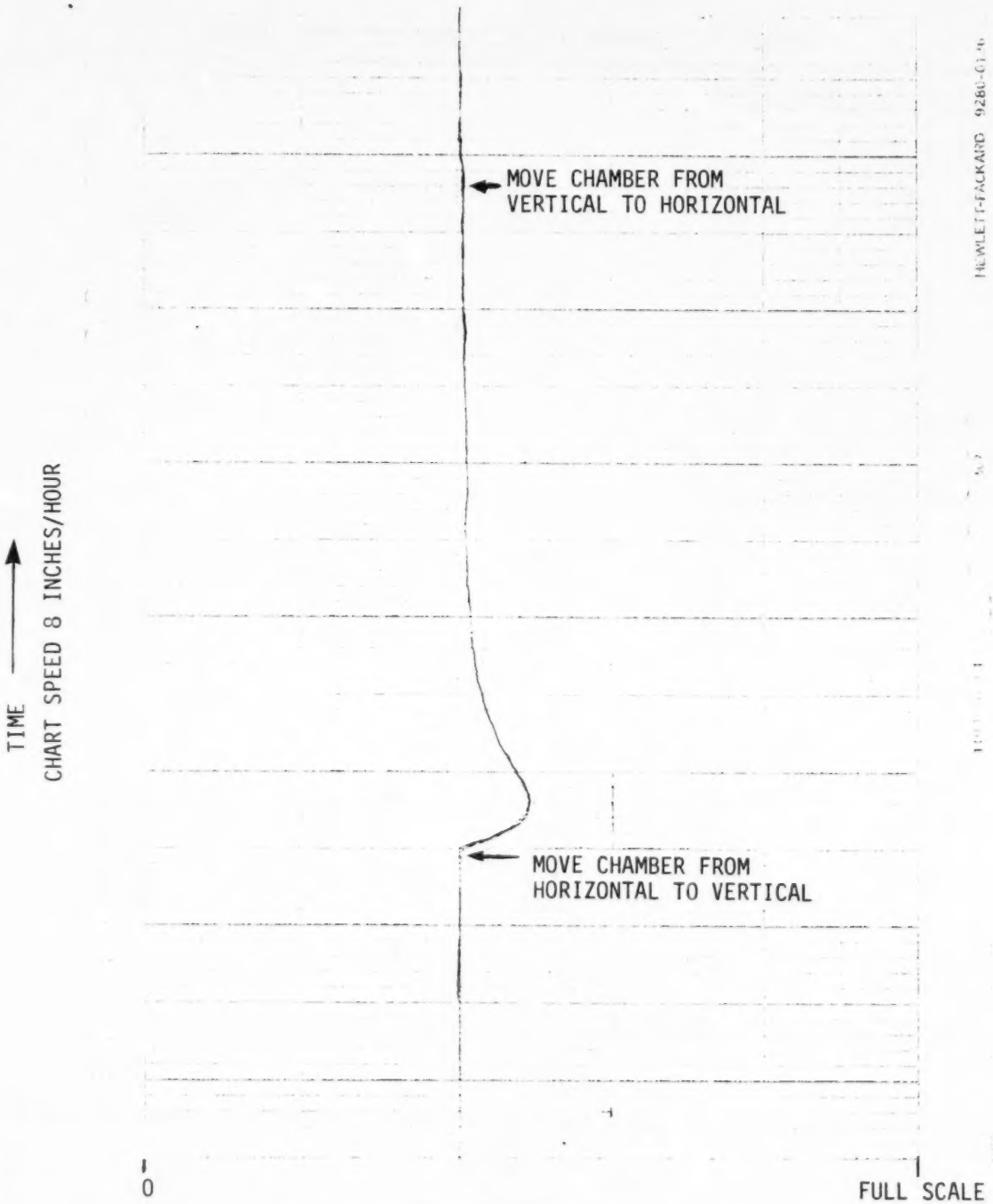
TABLE 14 (continued)

C. 10.0 cm permeation tube

| FLOW CC/MIN | OVEN POSITION | $SO_2$ OBSERVED, PPM | OVEN TEMPERATURE THERMISTOR(V) | | BENDIX °C |
|---|---|---|---|---|---|
| 5.0 | horizontal | .343 | .549 | (30.00°C) | 30.00 |
| | vertical | .345 | .549 | (30.00°C) | 30.00 |
| | horizontal | .346 | .549 | (30.00°C) | 30.00 |
| 10.0 | horizontal | .345 | .549 | (30.00°C) | 30.00 |
| | vertical | .345 | .549 | (30.00°C) | 30.00 |
| | horizontal | .343 | .549 | (30.00°C) | 30.00 |
| 25.0 | horizontal | .348 | .549 | (30.00°C) | 30.00 |
| | vertical | .346 | .549 | (30.00°C) | 30.00 |
| | horizontal | .346 | .549 | (30.00°C) | 30.00 |
| 50.0 | horizontal | .346 | .549 | (30.00°C) | 30.00 |
| | vertical | .346 | .549 | (30.00°C) | 30.00 |
| | horizontal | .344 | .549 | (30.00°C) | 30.00 |
| 100.0 | horizontal | .345 | .549 | (30.00°C) | 30.00 |
| | vertical | .346 | .549 | (30.00°C) | 30.00 |
| | horizontal | .346 | .549 | (30.00°C) | 30.00 |

TABLE 15. EFFECT OF $SO_2$ PERMEATION TUBE LENGTH

| FLOW OVER PERMEATION TUBE CC/MIN | $SO_2$ REPORTED, PPM | PERMEATION OVEN TEMPERATURE THERMISTOR, V | | BENDIX °C |
|---|---|---|---|---|
| 2.0 cm Tube (NBS 29-99) | | | | |
| 5.0 | .309 | .549 | (30.00°C) | 30.00 |
| 10.0 | .314 | .549 | (30.00°C) | 30.00 |
| 25.0 | .317 | .549 | (30.00°C) | 30.00 |
| 50.0 | .320 | .549 | (30.00°C) | 30.00 |
| 100.0 | .320 | .549 | (30.00°C) | 30.00 |
| AVERAGE | .316 | | | |
| 5.0 cm Tube (NBS 27-12) | | | | |
| 5.0 | .329 | .551 | (29.92°C) | 30.00 |
| 10.0 | .330 | .550 | (29.96°C) | 30.00 |
| 25.0 | .338 | .550 | (29.96°C) | 30.00 |
| 50.0 | .335 | .550 | (29.96°C) | 30.00 |
| 100.0 | .332 | .550 | (29.96°C) | 30.00 |
| AVERAGE | .333 | | | |
| 10.0 cm Tube (NBS 27-13) | | | | |
| 5.0 | .345 | .549 | (30.00°C) | 30.00 |
| 10.0 | .344 | .549 | (30.00°C) | 30.00 |
| 25.0 | .347 | .549 | (30.00°C) | 30.00 |
| 50.0 | .345 | .549 | (30.00°C) | 30.00 |
| 100.0 | .346 | .549 | (30.00°C) | 30.00 |
| AVERAGE | .345 | | | |
| Repeat 2.0 cm Tube (NBS 35-16) | | | | |
| 5.0 | .319 | .551 | (29.92°C) | 30.00 |




5.0 cm $SO_2$ Permeation Tube
5 cc/minute purge flow rate

FIGURE 25. TYPICAL STRIP CHART TRACE, $SO_2$ STUDY

TABLE 16. EFFECT OF COOLING ON MODIFIED BENDIX 8861P CALIBRATOR

5 CC/MIN. PURGE FLOW

| TIME | $SO_2$ OBSERVED, PPM | ENVIRONMENTAL CHAMBER T°C | SULFUR OVEN THERMISTOR(V) | | BENDIX °C |
|---|---|---|---|---|---|
| 1300 | .317 | 22.1 | - | - | - |
| 1315 | .319 | 23.8 | - | - | - |
| 1330 | .318 | 23.2 | - | - | - |
| 1345 | .321 | 23.3 | .551 | (29.92°C) | 30.00 |
| 1400 | .318 | 23.3 | .551 | (29.92°C) | 30.00 |
| 1415 | .322 | 23.8 | .551 | (29.92°C) | 30.00 |
| 1430 | .317 | 23.3 | .550 | (29.96°C) | 30.00 |
| 1445 | .319 | 23.0 | .550 | (29.96°C) | 30.00 |
| 1500 | .320 | 22.8 | .551 | (29.92°C) | 30.00 |
| Mean | .319 | | | | |
| SD | .002 | | | | |
| 1515 | .329 | 10.0 | .552 | (29.87°C) | 30.00 |
| 1530 | .335 | 9.0 | .557 | (29.63°C) | 30.00 |
| 1545 | .336 | 8.0 | .561 | (29.45°C) | 30.05 |
| 1600 | .334 | 8.0 | .564 | (29.28°C) | 30.05 |
| 1615 | .334 | 8.0 | .566 | (29.18°C) | 30.05 |
| 1630 | .331 | 8.0 | .567 | (29.14°C) | 30.05 |
| 1645 | .330 | 8.0 | .568 | (29.08°C) | 30.05 |
| 1700 | .330 | 8.0 | .568 | (29.08°C) | 30.05 |
| Mean | .332 | | | | |
| SD | .003 | | | | |

TABLE 17. EFFECT OF HEATING ON MODIFIED BENDIX 8861 CALIBRATOR

5 CC/MIN. PURGE FLOW

TRIAL 1

| TIME | $SO_2$ OBSERVED, PPM | ENVIRONMENTAL CHAMBER T°C | THERMISTOR | SULFUR OVEN | BENDIX °C |
|---|---|---|---|---|---|
| 1000 | .323 | 25.0 | .548 | (30.05°C) | 30.00 |
| 1030 | .321 | 24.1 | .548 | (30.05°C) | 30.00 |
| 1300 | .322 | 24.6 | .548 | (30.05°C) | 30.00 |
| 1330 | .321 | 24.4 | .548 | (30.05°C) | 30.00 |
| Mean | .322 | | | | |
| SD | .001 | | | | |
| 1400 | .328 | 38.9 | .545 | (30.20°C) | 29.95 |
| 1415 | .325 | 36.2 | .541 | (30.40°C) | 29.95 |
| 1430 | .328 | 41.8 | .540 | (30.45°C) | 29.95 |
| 1445 | .327 | 39.0 | .538 | (30.55°C) | 29.95 |
| 1500 | .327 | 37.8 | .538 | (30.55°C) | 29.95 |
| 1515 | .318 | 37.8 | .538 | (30.55°C) | 29.95 |
| 1530 | .328 | 37.7 | .538 | (30.55°C) | 29.95 |
| 1545 | .327 | 38.2 | .538 | (30.55°C) | 29.95 |
| 1600 | .327 | 38.1 | .538 | (30.55°C) | 29.95 |
| Mean | .326 | | | | |
| SD | .003 | | | | |

TRIAL 2

| | | | | | |
|---|---|---|---|---|---|
| 0845 | .340 | 23.7 | .550 | (29.96°C) | 30.00 |
| 0900 | .341 | 23.9 | .549 | (30.00°C) | 30.00 |
| 0915 | .341 | 24.1 | .549 | (30.00°C) | 30.00 |
| 0930 | .343 | 24.1 | .549 | (30.00°C) | 30.00 |
| 0945 | .342 | 23.9 | .549 | (30.00°C) | 30.00 |
| 1000 | .341 | 24.1 | .549 | (30.00°C) | 30.00 |
| 1015 | .337 | 24.0 | .549 | (30.00°C) | 30.00 |
| 1030 | .338 | 23.9 | .549 | (30.00°C) | 30.00 |
| Mean | .340 | | | | |
| SD | .002 | | | | |
| 1045 | .336 | 32.0 | .548 | (30.05°C) | 30.00 |
| 1100 | .337 | 33.0 | .547 | (30.10°C) | 30.00 |
| 1115 | .337 | 33.4 | .545 | (30.21°C) | 30.00 |
| 1130 | .339 | 33.4 | .544 | (30.25°C) | 30.00 |
| 1145 | .338 | 33.6 | .543 | (30.30°C) | 30.00 |
| 1200 | .338 | 32.5 | .543 | (30.30°C) | 30.00 |
| 1215 | .337 | 32.3 | .543 | (30.30°C) | 30.00 |
| 1230 | .334 | 32.1 | .543 | (30.30°C) | 30.00 |
| Mean | .337 | | | | |
| SD | .002 | | | | |

increase in analyzer response was observed following the exchange of a 10 cm tube for the 5 cm tube. A recheck of the 2 cm tube agreed within 1%. The time allowed for equilibration of the permeation tubes after exchange ranged from 16 hours to two days.

Although the effect of permeation tube length on analyzer response appears significant, conclusions do not seem warranted. Of necessity, due to equipment limitations, the study period associated with the exchange and equilibration of permeation tubes was two weeks in duration. The precision of the measuring system over the two week period of time may be no better than the magnitude of the apparent effect of permeation tube length on analyzer response.

The data in Table 16 indicate an adverse effect of cooling on the Bendix calibrator. The permeation tube chamber purge air temperature dropped from the normal control temperature of 30.0°C to a low of 29.1°C as the environmental chamber temperature decreased 15°C. The $SO_2$ concentration observed at the analyzer, however, increased. The reason for the increase was not determined. The dilution air flow controlling orifices in the calibrator, normally thermostated, were observed to be operating below the normal control temperature during the cooling test as indicated by continuous heater operation. The dilution air mass flow meter, however, did not indicate a change in dilution airflow.

The only effect of heating on the Bendix calibrator that was observed was a rise in the purge air temperature from the normal control temperature of 30.0°C to 30.6°C indicating an inefficiency in the thermoelectric cooling assembly control. No significant change in $SO_2$ concentration was observed at the analyzer during the course of the test. Trial 1 and trial 2 were conducted under seemingly identical conditions several days apart. The only variable known to have changed was the air scrubber (Ascarite was changed). The difference in analyzer response at room temperature of 5% between the two trials would appear to be an estimation of the precision of the measuring system employed.

During the course of this study, the most significant problem observed in regard to the routine operation of the Bendix calibrator was the difficulty

in obtaining a complete seal of the permeation tube chamber after the replacement of a permeation tube. Even a relatively minor leak was observed to be of consequence with a purge airflow rate of only 5 cc/minute. The problem was aggravated at high dilution airflow rates where significant back pressure forced additional leakage. A new permeation tube holder designed to eliminate this problem and to provide adequate purge air temperature control was designed, fabricated, and installed. A description of the holder is included in Appendix B.

The study described in this section was performed during the final phase of the Task Order. The modified calibrator resulted from experience gained during the course of the study. It is apparent from the data obtained that the Bendix calibration system, as originally supplied by the vendor, may have had limitations in routine operation, particularly in regard to audit work performed at low ambient temperatures.

# APPENDIX A

# AUDIT PROCEDURES FOR RAPS INSTRUMENT SYSTEMS

CONTENTS


Figures 73

Tables 73

A.1 Introduction 74

A.1.1 Preparation of Bendix Calibration/Audit Equipment 74

A.2 Calibration of Winnebago Instrumentation 81

A.2.1 Calibration of the Tracor Model 270HA Atmospheric Sulfur Analyzer 81

A.2.2 Calibration of the Monitor Labs Model 8440 Oxides on Nitrogen Analyzer 84

A.2.2.1 Ozone Generator 87

A.2.3 Bendix Ozone Analyzer 89

A.2.4 Calibration of MRI 1561 Nephelometer 90

A.3 Audit Procedures 92

A.3.1 Sulfur Analyzer Audits 92

A.3.2 Oxides of Nitrogen Analyzer Audit 92

A.3.3 Ozone Analyzer Audit 94

A.3.4 MRI 1561 Nephelometer Audit 96

A.3.5 Audit Procedure for Atmospheric Methane, Carbon Monoxide and Total Hydrocarbons 96

A.4 Air Management 98

FIGURES


| Number | | Page |
|---|---|---|
| A.1 | Bendix 8861D Flow Diagram | 75 |
| A.2 | Bendix 8861P Flow Diagram | 76 |
| A.3 | Typical Calibration Curve for Bendix 8861D | 78 |
| A.4 | Typical Interconnections for Introduction of Calibration Gas into Instrument to be Calibrated or Audited | 82 |
| A.5 | Conversion Efficiency Determination | 94 |


TABLES


| Number | | Page |
|---|---|---|
| A.1 | Sulfur Dioxide Calibration: Typical Bendix 8861 Settings | 83 |
| A.2 | Settings for $NO_X$ Analyzer | 85 |
| A.3 | Oxides of Nitrogen Calibration: Typical Bendix 8861D Settings | 86 |
| A.4 | Sample Tabulation for a NO - $O_3$ Titration | 88 |
| A.5 | Values for Ozone Calibration | 89 |
| A.6 | Sample Table to be Used in the $NO_X$ - NO Audit | 93 |
| A.7 | Settings to use on Bendix Calibrator to Produce Various Ozone Concentrations | 95 |
| A.8 | Values for Ozone Audit at High Lamp Output | 95 |

## A.1 INTRODUCTION

The following procedures were established and tested during the initial stages of work on Task Order 106. The procedures are presented in logical sequence and related to both routine audit procedures, as well as the routine calibration work performed, utilizing the pollutant monitoring equipment aboard the Winnebago van.

### A.1.1 PREPARATION OF BENDIX CALIBRATION/AUDIT EQUIPMENT

1. Calibration curves used to read air and gas flows from the Bendix instruments must be developed as follows (reference Figures A.1 and A.2):

a) Break the connection at the brass "T" upstream of pressure regulator PR-2 on the 8861D and cap off the side of the "T" leading to the instrument filter.

b) Attach a zero air cylinder to the 8861D at the "clean air" port using a length of 1/4" tubing. Set the cylinder regulator delivery pressure to 40 PSI.

c) Starting with pressure regulators PR-1 and PR-2 closed and orifice No. 2, 3, 4, 5 closed, connect the 8861D "out" port to a 1000 cc bubble tube.

d) Open PR-2 to 10% of gauge as monitored by pressure gauge P2 and measure the air flow rate at the "out" port using the bubble tube. Repeat this procedure at 20%, 30%, etc., to 100% of gauge.

e) Repeat d) above with orifice No. 1 and No. 2 open.

f) Repeat d) above with orifice No. 1 and No. 3 open.

g) Repeat for the remaining orifices and all combinations of orifices, i.e., finish with 1+2+3+4+5 for maximum flow through

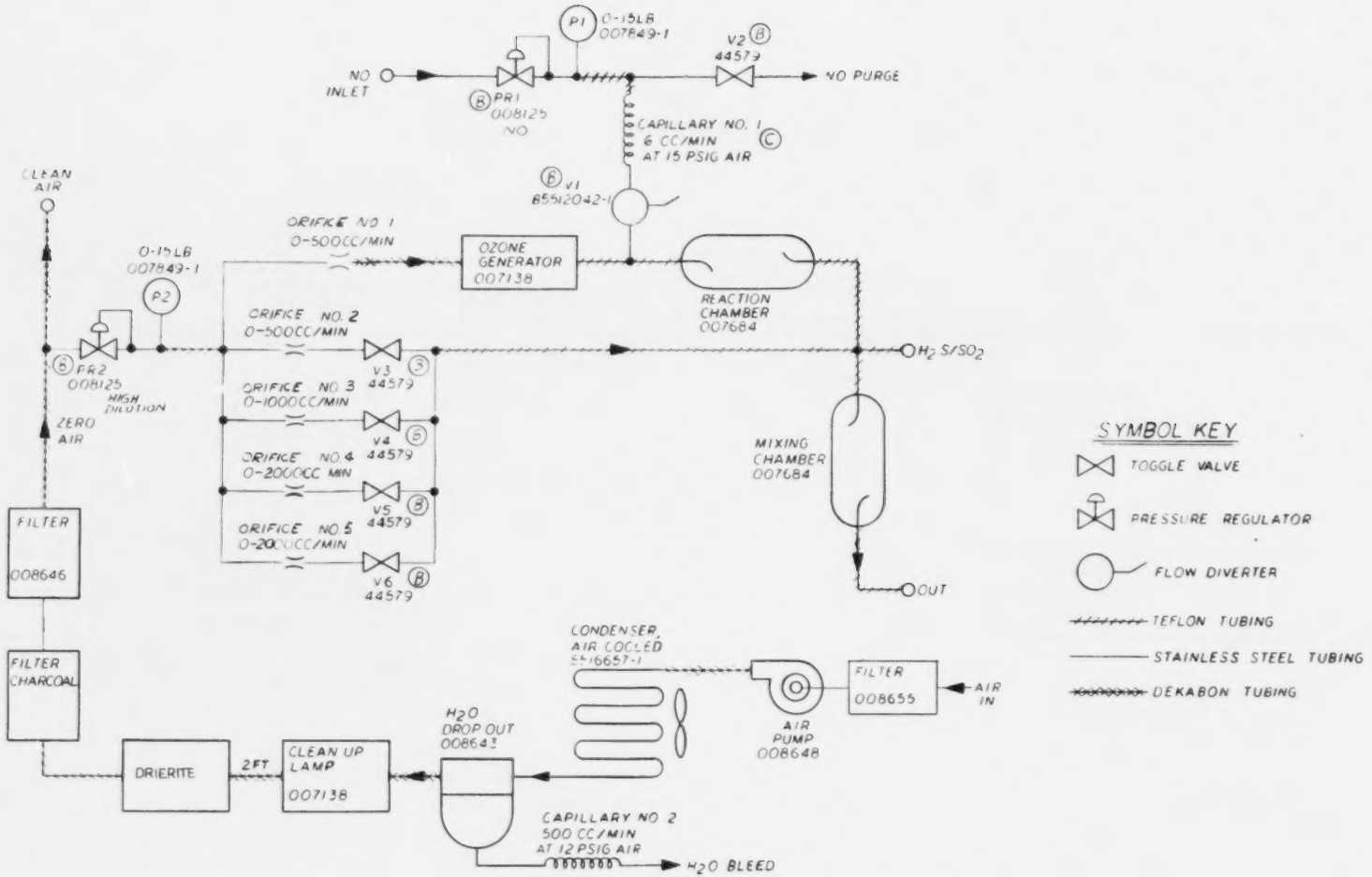



FIGURE A.1. BENDIX 8861D FLOW DIAGRAM

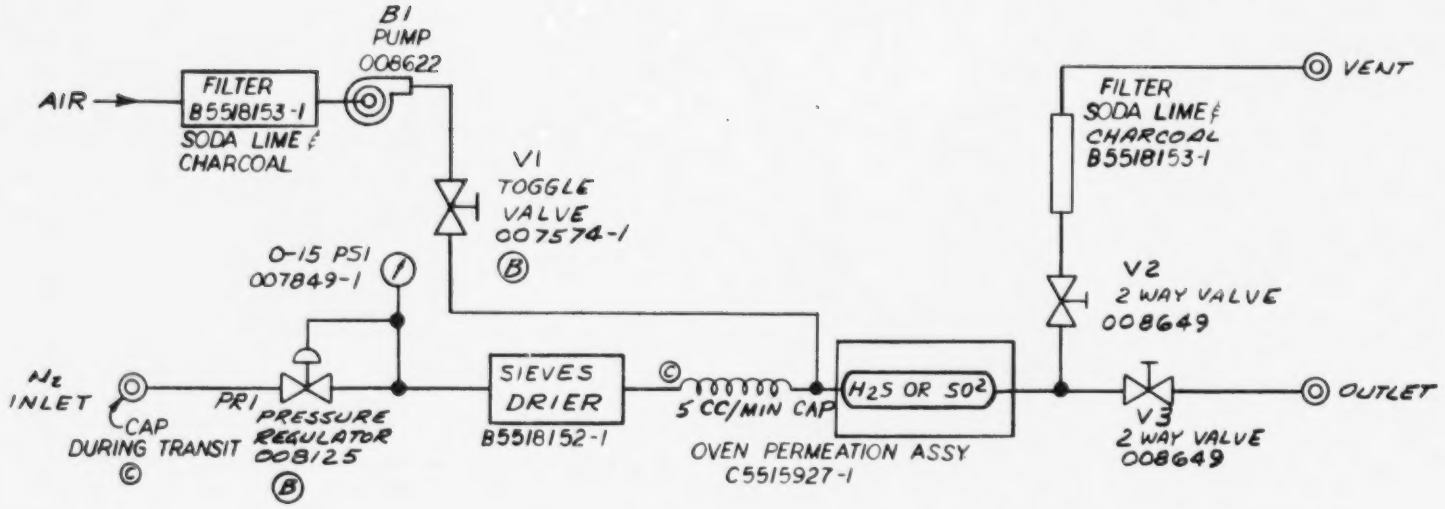



FIGURE A.2. BENDIX 8861P FLOW DIAGRAM

the 8861D.

h) Repeat the above procedure and calibrate the nitric oxide capillary using nitrogen entering the "NO Inlet". Flow from the capillary to a 10 cc bubble tube can be taken at the NO "pull-to-test" valve.

i) Repeat the above procedure and calibrate the capillary upstream of 8861P permeation oven. Close V1 toggle valve (off position), introduce zero air into the "$N_2$" port and with V2 closed and V3 open, attach a 10 cc bubble tube to the 8861P outlet port for the flow calibration.

j) After converting all of the flows to cc/minute for each of the 10% gauge increments, the flows must be corrected to standard temperature of 0°C and standard pressure of 760 mm Hg by multiplying each reading by a factor. The correction factor is derived as follows:

23.5°C = temperature in lab at time of calibration

746.3 mm mercury, barometric pressure in lab at time of calibration.

$$\text{Correction Factor} = \frac{273}{273 + \text{Ambient Temperature}} \times \frac{\text{Bar. Press. in mm Hg}}{760}$$

$$CF = \frac{273}{273 + 23.5} \times \frac{746.3}{760} = 0.9041$$

Graphs are now prepared by plotting "Gauge Reading - % of scale" as the ordinate and "cc/minute" along the abscissa. This will facilitate reading any flow within the range of the capillary or orifice under study (see Figure A.3).

2. With Bendix 8861P set on "stand-by", the internal air pump is operative and keeps a flow of air through the permeation oven. If this pump is shut off, twelve to twenty-four hours are required to re-establish equilibrium condition within the permeation oven. Assuming an equilibrium condition with the permeation oven temperature at 30°C $\pm$ 0.02°C (running for twelve to

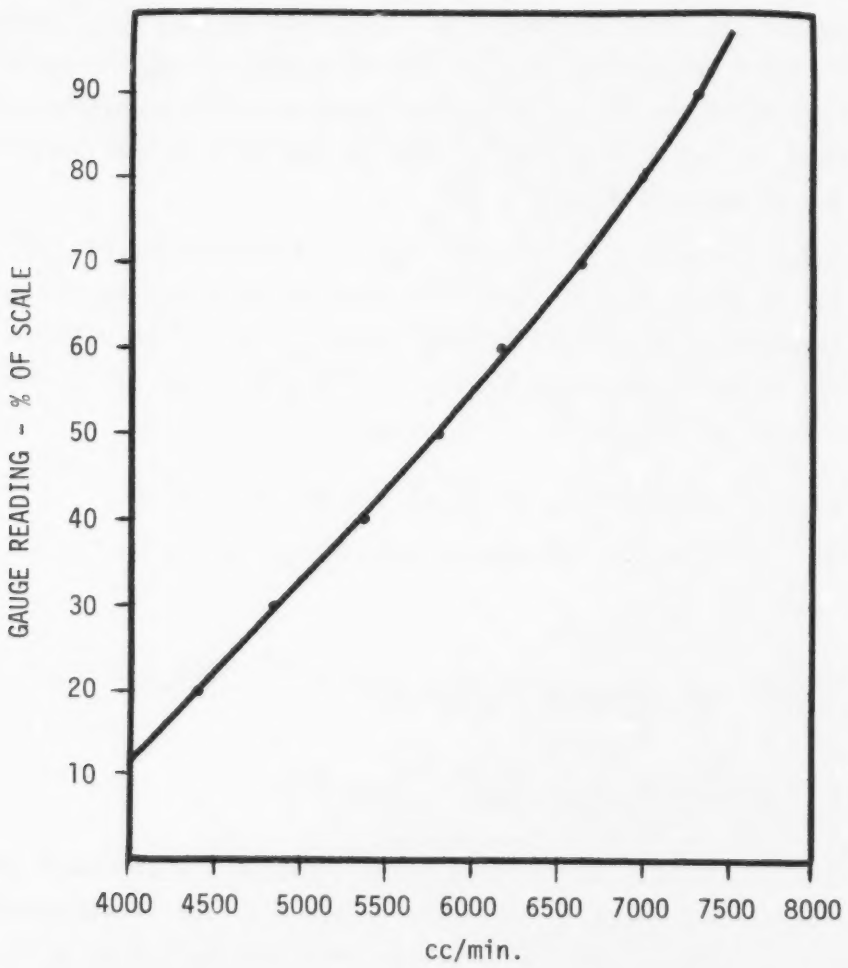



FIGURE A.3 TYPICAL CALIBRATION CURVE FOR BENDIX 8861D

twenty-four hours on 115 VAC with power switch in ON position, V1 toggle valve in OFF position and PR-1 pressure regulator set to 100% of scale on the 0-15 psig) prepare the 8861D for operation.

3. Turn the power switch on the Bendix 8861D to the ON position, turn OFF V3, 4, 5, 6 (corresponding to orifices 2, 3, 4 and 5). Connect a 1/4" Teflon line between the 8861D "clean air" port and the $N_2$ inlet on the 8861P. The 8861D is now providing zero air to the 8861P where it will flow through the 5 cc/min capillary and purge the permeation oven. At this point, the permeation tube oven effluent will exit either through the "vent" or through the "outlet" depending on the settings on V2 and V3 (V3 open, V2 closed, gas goes to "outlet". V3 closed, V2 open, gas goes through scrubber to "vent").

The Bendix 8861D can produce air of quality adequate for conducting all of the standard audits except for the Beckman 6800. Scrubbed air of good quality is possible if scrubbers are installed as follows: remove the "U" tube connector between the air surge tank and the particulate filter. At the outlet of the surge tank install a short line leading to a "Drierite" scrubber filled with indicating Drierite. In series with the Driertie scrubber install a second Drierite column charged with cocoanut shell charcoal, 6-14 mesh. The outlet from the charcoal scrubber is attached to the Bendix particulate filter.

4. Before calibrations or audits actually begin it is necessary to point out certain pitfalls which must be avoided.

a) Standards. The NO gas cylinders used in this work must be certified as to exact composition, i.e., NBS or directly traceable to an NBS cylinder. For the CO, $CH_4$, THC audits and calibrations, cylinders of known composition will be used and again, these must be certified as traceable to NBS or certified as to exact composition by RTP. Sulfur dioxide permeation tubes purchased directly from NBS will be used in the Bendix 8861P and the permeation oven will be operated at 30°C $\pm$ .02°C to insure an accurate output of $SO_2$.

Since the FID response of most hydrocarbon analyzers is sensitive to oxygen concentration, it is necessary for zero air and matrix air (in the standard cylinders) to have the same oxygen content as ambient air. Similarly, for TS analyses employing flame photometric detectors, the matrix air must have the same $CO_2$ content as ambient air.

b) Flow rates. Every instrument audited has a specific sample flow rate and it is necessary to insure that the flow of calibration gas (from the Bendix 8861D) exceeds the analyzer demand. Good practice dictates a procedure whereby a rotameter is used to measure the sample flow of any instrument when the demand is unknown. The flow as measured by the rotameter must then be exceeded when preparing calibration gas to avoid taking in ambient air along with the calibration/audit gas entering the sample port of the instrument under test.

c) Materials used. Since $SO_2$ and $O_3$ both are quite reactive it is mandatory to always convey these gases in glass and/or Teflon. Span gases containing nitric oxide, carbon monoxide, methane, or other hydrocarbons are less critical but nevertheless conveyed in Teflon tubing.

d) Distinction between "audit" and "calibration". When the operator is instructed to calibrate an instrument, known gas compositions are introduced and the instrument is adjusted to respond in accordance with the known gas composition. This is accomplished in accordance with the instructions given in the manual for that instrument and involves changing instrument dial settings, potentiometer adjustments and any other adjustment necessary to cause the instrument to read the same value as the gas being introduced. An audit on the other hand involves absolutely no instrument adjustment. A known composition gas is introduced and the instrument read-out is taken and recorded.

## A.2 CALIBRATION OF WINNEBAGO INSTRUMENTATION

The Winnebago van is equipped with a full complement of air quality analyzers for use in preparation of the Bendix 8861 calibration system for audit activities and for use in running "side-by-side" field comparisons in proximity to existing air quality monitoring sites. The following procedures relate to the calibration of this instrumentation for the above mentioned purposes.

### A.2.1 CALIBRATION OF THE TRACOR MODEL 270HA ATMOSPHERIC SULFUR ANALYZER

Figure A.4 depicts the interconnection described in the following paragraphs and should be referenced for clarity.

1. Connect a 1/4" Teflon line between 8861D "out" port and the normally open port of the input solenoid valve of the Tracor. Provide a "T" connection or a glass manifold in this line to vent excess gas delivered by the 8861D.

2. Provide zero air input to Tracor as follows:

   a) A 1/4" Teflon line should be connected between the 8861D "out" and the Tracor input (through a "T" or manifold as previously described). With the 8861D operating, adjust pressure gauge P-2 to 50% with valve (orifice) 5 in ON position. Zero air at the rate of 3000 cc/min is now leaving the 8861D.

   b) Set a DVM on 0-5 volt range.

   c) Connect the DVM as follows: one set of leads to "TS low" and "gnd" and another set of leads to "$SO_2$ low" and "gnd". These connections are on the rear of the Tracor on the terminal strips marked "TB2". The two sets of leads are alternately plugged into the DVM to read sulfur dioxide or total sulfur.

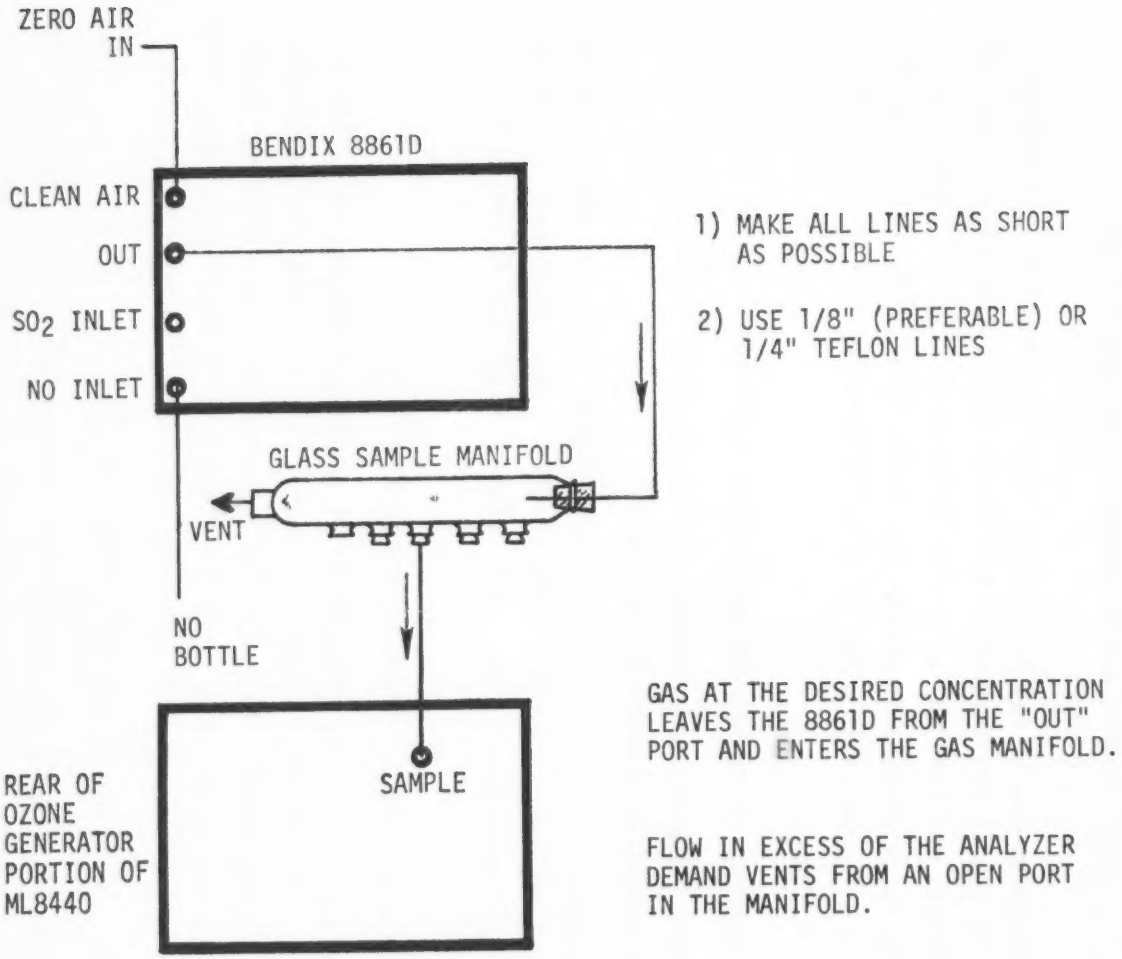



FIGURE A.4 TYPICAL INTERCONNECTIONS FOR INTRODUCTION OF CALIBRATION GAS INTO INSTRUMENT TO BE CALIBRATED OR AUDITED

3. Allow the analyzer to sample zero air for fifteen minutes and then take a voltage reading. Record sulfur dioxide and total sulfur voltages on each channel.

4. Connect a short length of 1/8" OD Teflon tubing between the 8861P "outlet" and the 8861D $H_2S/SO_2$ inlet. Sulfur dioxide gas is now entering the 8861D so that it may be diluted to the desired concentration.

5. Run a calibration recording voltages as explained above and using the following typical table (Table A.1) to obtain the desired dilutions.

TABLE A.1 SULFUR DIOXIDE CALIBRATION: TYPICAL BENDIX 8861 SETTINGS

| Dilution Concentration Desired (PPB)** | $F_d$* + $F_p$ | Orifice Used | Percent of Gauge | Station Voltage $SO_2$ TS |
|---|---|---|---|---|
| 0 | - | - | - | |
| 50 | 7220 + 7 | 1, 2, 3, 4, 5 | 69 | |
| 60 | 6015 + 7 | 1, 2, 3, 4, 5 | 43 | |
| 70 | 5155 + 7 | 1, 2, 3, 4, 5 | 26 | |
| 90 | 4008 + 7 | 1, 4, 5 | 25 | |
| 100 | 3607 + 7 | 1, 4, 5 | 16 | |
| 150 | 2402 + 7 | 1, 4 | 30.5 | |
| 190 | 1895 + 7 | 1, 3 | 72 | |
| 300 | 1197 + 7 | 1, 2 | 14.5 | |
| 500 | 715 + 7 | 1 | 91 | |
| 700 | 509 + 7 | 1 | 35 | |
| 900 | 395 + 7 | 1 | 12 | |

* Where $F_p$ = cc/minute of $SO_2$ air delivered by 8861P (through permeation tube oven at 30.00°C) and

$F_d$ = cc/minute of air delivered by the 8861D diluter.

** Calculated using NBS permeation tube 21-71 with a permeation rate of .946 micrograms/minute at 30°C.

The calibration is run by selecting four or more points from the table and recording the voltages at each of the selected dilution settings. A graph is then plotted to determine response linearity.

6. In the event additional points are required, they are calculated as follows:

$$C_{ppm} = \frac{PR \times K}{F_p + F_d}$$

Where $C_{ppm}$ = desired concentration in parts per million

PR = permeation rate in ng/min (Ref. to oven temperature.)

K (Ref. to 0°C and 760 mm Hg) = $\frac{22.4}{\text{Molecular wt. of perm. gas}}$

(22.4L of an ideal gas = 1.00 mole at 0°C, 760 mm Hg)

$F_p$ = cc/minute from the 8861P permeation device

$F_d$ = cc/minute from the 8861D dilution device

EXAMPLE: The 2.0 cm $SO_2$ permeation tube is NBS certified to deliver 946 ng/min at 30°C. To calculate the dilution air flow rate corresponding to a desired gas concentration:

$$\text{Flow Rate (cc/min)} = \frac{(946)\left(\frac{22.4}{64}\right)}{\text{Desired Concentration ppm}}$$

Desired flow rates are read off the calibration curves developed for the orifices in these instruments. These curves are kept with the service manuals.

A.2.2 CALIBRATION OF THE MONITOR LABS MODEL 8440 OXIDES OF NITROGEN ANALYZER

1. Inspect rear panel of the analyzer unit and the sample conditioning unit and check the following items:

a) Drier connected to brass air inlet

b) Teflon NO line connected between modules

c) Teflon $NO_X$ line connected between modules

d) Teflon ozone line connected between modules

e) Teflon sample inlet line connected to glass sample manifold (see Figure A.4).

f) Glass sample manifold should be connected to the 8861D output

2. Connect the nitric oxide source gas (typically 100 ppm NO in nitrogen) to 8861D NO inlet.

3. Turn on the main power and the ozone generator power on $NO_X$ analyzer.

4. Adjust vacuum gauge to 20 inches. This results in rotometer flows as follows:

$NO_X$ - between 150-200 cc/min

NO - between 150-200 cc/min

Ozone - between 100-150 cc/min

5. Connect a DVM to the DVM terminal blocks on the rear of the instrument. Use the NO terminals.

6. Connect a 0-1 volt recorder to the terminal posts on the front of the instrument and adjust instrument settings as shown in Table A.2.

TABLE A.2 SETTINGS FOR $NO_X$ ANALYZER

| Channel | Sec. | Range | Vac. | Flow |
|---|---|---|---|---|
| $NO_X$ | 20 | 2 | 20 | 175 |
| NO | 20 | 2 | -- | 225 |
| | | | | Ozone = 100 |

7. Start the Bendix diluter and adjust for 3000 cc/min zero air. Allow the analyzer to sample the zero air and then adjust both NO and $NO_X$ channels using the respective zero potentiometers to give zero volts on the DVM (or a slight positive off-set if this is desirable).

8. Introduce each span gas concentration in turn selecting points and conditions as shown in Table A.3.

TABLE A.3 OXIDES OF NITROGEN CALIBRATION: TYPICAL BENDIX 8861D SETTINGS

| Dilution Concentration Desired (ppm) | $F_p + F_d$ * | Orifice Used | Percent of Gauge P1 | $F_p$ cc/min | $P_2$ Gauge Setting |
|---|---|---|---|---|---|
| 0.45 | 467 | 1 | 38.5 | 2.0 | 34 |
| 0.35 | 601 | 1 | 38.5 | 2.0 | 72 |
| 0.25 | 841 | 2 | 38.5 | 2.0 | 24.5 |
| 0.20 | 1052 | 2 | 38.5 | 2.0 | 50.5 |
| 0.15 | 1402 | 3 | 38.5 | 2.0 | 37.5 |
| 0.05 | 4208 | 3, 4, 5 | 38.5 | 2.0 | 22.5 |

* Where $F_p$ = cc/min of NO from the cylinder

$F_d$ = cc/min of air delivered through the 8861D orifices

Calculation of other points can be accomplished using the following equations:

$$\frac{(\text{NO conc. in cylinder, ppm}) \times F_p}{F_p + F_d} = \text{NO concentration, ppm}$$

For example, if a final concentration of .05 ppm $NO_x$ is desired, and the concentration of NO in the cylinder is known to be 105.2 ppm, we can fix $F_p$ at 2 cc/min by setting $P_1$ to 38.5% of gauge. $F_d$ can be determined from the above equation or:

$$(F_p + F_d) = \frac{(105.2) \times (2)}{0.05} = 4210 \text{ cc/min}$$

Since $F_p$ is set at 2 cc/min, $F_d$ = 4208 cc/min. This can be achieved by setting $P_2$ to 22.5% and opening orifice 3, 4 and 5.

9. Determination of efficiency of $NO_2$ to NO converter. Proceed as follows:

a) Starting with both channels properly zeroed, introduce diluted NO to the calibrated analyzer to read 1.5 - 2.0 ppm NO.

b) When equilibrium is achieved, observe that equal response obtained on the NO and $NO_X$ channels.

c) Reverse the channels to check for NO purity.

d) Turn on the $O_3$ generator within the Bendix 8861D. Wait 10 minutes.

e) Adjust the Bendix $O_3$ generator so NO reading is reduced to 50% of original reading. Record stable NO and $NO_X$ values. The drop in NO concentration is equal to the concentration of $NO_2$ formed in accordance with the reaction equation

$$NO + O_3 = NO_2 + O_2$$

f) Calculate efficiency

$$\% E = \left(1 - \frac{NO_X \text{ (Orig.)} - NO_X \text{ (Final)}}{NO \text{ (Orig.)} - NO \text{ (Final)}}\right) \times 100$$

A.2.2.1 Ozone Generator

Immediately following the calibration of the oxides of nitrogen analyzer and prior to the calibration of the ozone analyzer, the ozone generator within the Bendix 8861D should be calibrated. To perform a gas phase titration of nitric oxide within the Bendix 8861D, it is first necessary to establish an equilibrium concentration of nitric oxide. This may be done using the techniques described in section A.2.2 in regard to the calibration of the oxides of nitrogen analyzer. The nitric oxide channel of the analyzer then serves to monitor the results of the titration occurring within the Bendix 8861D. All that is required to perform the titration is to turn on the ozone generator in the calibrator. Air flowing through orifice 1 will pass over the ultraviolet lamp, undergo irradiation, and meet with nitric oxide in a glass reaction chamber. The reacted mixture leaves the reaction chamber

and is diluted in the mixing chamber. The residual nitric oxide concentration after ozone titration is then observed using the nitric oxide channel of the analyzer. A step by step example is as follows:

Proceed initially as explained in section A.2.2 to prepare the Bendix 8861D and a Monitor Labs 8440 oxides of nitrogen analyzer. Establish zero air flow either from the Bendix calibrator or from a cylinder to the sampling manifold and subsequently to the sample inlet port of the 8440. Zero the analyzer using the zero potentiometer. Establish an initial nitric oxide concentration of 0.8 ppm. A typical set of conditions using a cylinder certified at 105.2 ppm NO is presented in Table A.4.

TABLE A.4 SAMPLE TABULATION FOR A NO - $O_3$ TITRATION

| Desired Conc., ppm | $P_1$ | $F_p$ | $P_2$ | $F_d$ | Orifice | Output, Volts NO | Output, Volts $NO_x$ |
|---|---|---|---|---|---|---|---|
| 0.80 | 80% | 4.0 | 49% | 522 | 1 | .800 | .800 |

$F_p + F_d = 526$ cc/minute

Once a stable trace is established on the recorder, the ozone generator is set to Range 500, Set Point 440 and the lamp is turned on. After a short time the NO channel will show a sharp decrease as ozone reacts with the NO. After ozone addition the nitric oxide concentration is measured again by monitoring the NO channel of the analyzer. In this particular example, the NO channel decreased to 0.400 volts. The ozone output is now calculated using the above information.

0.800 (original voltage before $O_3$ addition)
0.400 (final voltage after ozone lamp was started)

0.400 difference

On the analyzer used the slope was 1.00 ppm/volt

0.400 x 1.00 = 0.400 ppm decrease in NO concentration

Since NO reacts with $O_3$ 1:1 stoichiometrically, this means 0.400 ppm ozone reacted in the diluted gas stream. To convert this figure to the

undiluted concentration delivered from the ozone lamp source we use

microliters of ozone/min = ppm ozone x dilution air, liters/min

or .400 x .526 = 0.2104

The lamp is now calibrated at an air flow of 0.526 liters/minute and is producing 0.2104 microliters of ozone per minute at standard temperature and pressure.

### A.2.3 BENDIX OZONE ANALYZER

Once the ozone generator in the Bendix 8861D has been calibrated, an ozone analyzer calibration may be performed. In this case the pressure setting on the capillary (No. 1) is not changed to insure a constant ozone production as dilution air is varied. Dilution air is added in this case only by using additional capillaries. To get the second point for the calibration we now open capillary No. 2 and readjust $P_2$ to 49%. The table below indicates the capillaries used and the resulting concentration. After each additional capillary is opened, $P_2$ must be readjusted to 49% to maintain a known standard air flow over the ozone lamp. Typical flow settings are shown in Table A.5.

TABLE A.5 VALUES FOR OZONE CALIBRATION

| Ozone Desired Conc. ppm | Orifice | Dilution Air LPM | $P_2$ |
|---|---|---|---|
| 0.40 | 1 | 0.526 | 49% |
| 0.20 | 1 + 2 | 1.055 | 49% |
| 0.10 | 1 + 3 | 2.104 | 49% |
| 0.083 | 1 + 4 | 2.550 | 49% |
| 0.040 | 1 + 2 + 3 + 4 | 5.320 | 49% |

sample calculation: $\frac{0.2104 \text{ ul/min } O_3}{0.526 \text{ LPM dil. air}} = 0.400$ ppm ozone

After the flow conditions have been established, perform the following steps to complete the five point calibration of the ozone analyzer.

1. Attach the Teflon output line from the Bendix 8861D to the sample input of the Bendix ozone monitor via a "T" or a glass manifold.

2. With power switch to "on" position (allow 120 minutes for warm-up), adjust ethylene flow to 25 cc/minute.

3. Set mode selector to ambient, time constant to 10 seconds, and range selector to 0.5 ppm.

4. The terminal block on the rear of the instrument may be used to display a DVM response to the calibration gas.

5. Select each point in turn as illustrated in Table A.5 to complete a five point calibration on the ozone instrument.

A.2.4 CALIBRATION OF MRI 1561 NEPHELOMETER

All pots and test points referred to in this procedure are located on the electronics board on the inside of the instrument front door. In all cases the voltages should be read with a digital volt meter connected to the red and black terminals located on the righthand side of the instrument. The meter on the face of the instrument should be used only as a rough indication of instrument behavior. In RAMS stations the data acquisition system digital display may be used with the analog signal appearing on channel 37.

The following steps should be followed in sequence.

1. Unhook the inlet hose and plug the intake.

2. Move the "air - operate - Freon" switch to the "air" position.

3. Plug the lower outlet and wait at least 15 minutes or until meter reading and/or voltage output are steady.

4. Readout should be 0.00 VDC$\pm$ .03; if not, adjust R-42 (background) for proper reading.

5. Connect a jumper from TP-1 to TP-8 on the electronic board. This should cause the light to go out. Readout should slowly return to 0.00 $\pm$

.03 VDC. If not, adjust R-61 (zero) for correct reading.

6. Repeat steps 5 and 6 until interaction is out of circuit.

7. Place "air - operate - Freon" switch in the "Freon" positon. Unhook the tubing coming from the top of the Y shaped tube fitting above the small clean air pump. Insert the delivery tube from the Freon bottle in the tubing and turn the valve on top of the bottle on. A flow-limiting orifice is in this valve so that proper flow occurs when the valve is fully open.

8. After readout becomes steady (15 minutes or more) the output voltage should be 1.00 $\pm$ .03 VDC. If not, adjust R-64 (Freon) for correct reading.

9. Connect jumper from TP-1 to TP-9. Readout should slowly rise to 4.00 $\pm$ .25 VDC. If not, adjust R-57 (calibrate) for correct reading.

10. Remove jumper and observe that readout returns to 1.00 $\pm$ .03 VDC. If not, adjust R-64 (Freon) for correct reading.

11. Repeat steps 9 and 10 until there is no interaction.

12. Unit is calibrated. Unplug air inlet and outlet, remove Freon connection and reconnect tubing to the top of the Y shaped tube fitting in the clean air system, reconnect inlet hose at top of instrument and move "air - operate - Freon" switch to "operate" position.

## A.3 AUDIT PROCEDURES

The audit work performed during the course of this study was in most part performed with the Bendix 8861 portable calibrator. Additional audit work was performed with standard gas cylinders introduced directly to the analyzer audited. All such procedures are outlined below.

### A.3.1 SULFUR ANALYZER AUDITS

Establish a flow of zero air from the manifold on the 8861D to the sample air inlet of the sulfur instrument under audit. The flow rate used is determined by the instrument under test. For example, an instrument such as the Sign-X uses 2.5 LPM while a Tracor uses only 0.360 LPM. Choose an air flow from the calibrator in excess of the demand of the instrument under audit. Once a zero air flow is established and the instrument output voltage is recorded, introduce the output from the 8861P into the dilution air and establish the highest sulfur concentration to be used in the audit. For example, when auditing a Tracor, set up to deliver 395 + 7 cc of zero air. (The 8861D is set at 12% of gauge ($P_2$) and orifice 1 is open as per Table A.1.) Connect the 1/8" Teflon line (the permeation oven output) to the input side of the dilution chamber on the 8861D. Sulfur dioxide gas is now being mixed in the dilution air in the proper proportions to give 0.900 ppm $SO_2$. After conditions have stabilized, read the voltage corresponding to 0.900 ppm $SO_2$. Next, using only orifice No. 1, set $P_2$ to 35% of gauge. The concentration of $SO_2$ is now at 0.700 ppm. Continue to add more dilution air as indicated in Table A.1 until four or more points (plus zero air) have been established.

### A.3.2 OXIDES OF NITROGEN ANALYZER AUDIT

Use a rotameter on the input of the instrument to check total sample flow which should be about 500 cc/minute.

Calculate the desired gas concentrations to be used to audit the instrument using the following equation:

$$\frac{(\text{NO conc. in Tank, ppm}) \times (\text{cc/min thru } V_1)}{(\text{cc/min thru } V_1) + (\text{cc/min thru } V_2)} = \text{NO concentration in ppm}$$

A table should be developed and used throughout this audit. An example of a calculation and an appropriate table is shown in Table A.6.

TABLE A.6 SAMPLE TABLE TO BE USED IN THE $NO_X$ - NO AUDIT

| Desired Conc. ppm | $P_1$ cc | $P_1$ % Gauge | $P_2$ cc | $P_2$ % Gauge | Orifice No. | $NO_X$ Volts | NO Volts |
|---|---|---|---|---|---|---|---|
| 0.40 | 4.0 | 80.5 | 910 | 33.0 | 1+2 | .808 | .808 |
| 0.30 | 4.0 | 80.5 | 1213 | 75.0 | 1+2 | .604 | .600 |
| 0.20 | 4.0 | 80.5 | 1820 | 81.0 | 1+3 | .390 | .390 |
| 0.10 | 4.0 | 80.5 | 3640 | 24.5 | 1+4+5 | .194 | .193 |
| 0.05 | 4.0 | 80.5 | 7280 | 88.0 | 1+2+3+4+5 | .094 | .092 |
| zero | 0 | 0 | 7290 | 88.0 | 1+2+3+4+5 | .004 | .002 |

Sample Calculation: $\frac{(91.0)\ (4.0)}{(0.40)} = 910$ cc/min flow

(91.0 ppm) = conc. of NO in NBS supply tank

(4.0) = cc/minute flow thru capillary 1

(0.40) = desired ppm of NO for first audit point

The flow is established for the first point (0.40 ppm of NO) and after the recorder indicates stable conditions the voltage is read on both channels. Next, $P_2$ is opened to 75% giving a flow of 1213 cc/minute. The NO concentration now flowing to the manifold is 0.30 ppm. Again, after conditions have stabilized a voltage reading is taken after the last reading (0.05 ppm). The NO tank is turned off and a zero air reading is taken.

The $NO_2$ converter in the oxides of nitrogen analyzer is challenged during the course of the audit by the partial conversion of nitric oxide to nitrogen dioxide prior to delivery to the analyzer audited. The results obtained by monitoring the nitric oxide (NO) and the oxides of nitrogen

($NO_X$) channels of the analyzer audited are used to determine the converter efficiency. As a typical example, the following audit data obtained at RAMS station 114 is presented.

| NO | | | $NO_X$ | | |
|---|---|---|---|---|---|
| Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) | Auditor Value (ppm) | Instrument Reading (volts) | Instr. Reading (ppm) |
| .450 | 4.8413 | .473 | .450 | 4.8217 | .483 |
| ozone added | 1.5258 | .146 | ozone added | 4.7998 | .480 |
| .350 | 3.7792 | .368 | .350 | 3.7792 | .377 |
| .250 | 2.6635 | .258 | .250 | 2.6684 | .264 |
| .150 | 1.6479 | .158 | .150 | 1.6074 | .163 |
| zero | .0341 | -.001 | zero | .0512 | -.001 |

$NO/NO_2$ CONVERTER EFFICIENCY: 99%

$$\text{Converter Efficiency} = 1 - \frac{(\text{ppm } NO_X,\ O_3 \text{ off}) - (\text{ppm } NO_X,\ O_3 \text{ on})}{(\text{ppm NO},\ O_3 \text{ off}) - (\text{ppm NO},\ O_3 \text{ on})} \times 100$$

FIGURE A.5 CONVERSION EFFICIENCY DETERMINATION

The partial conversion of nitric oxide is achieved by energizing the ozone generator within the Bendix auditor just after the establishment of an equilibrium analyzer response to the first audit nitric oxide concentration delivered at .45 ppm (in this example). The equilibrium response after ozone addition is recorded for both the NO channel and the $NO_X$ channel. Conversion efficiency is then calculated as indicated in Figure A.5.

### A.3.3 OZONE ANALYZER AUDIT

Prior to the audit of every ozone analyzer, it is advisable to check the output of the ozone source in the Bendix 8861D by performing a NO-$O_3$ titration. A convenient time for this check will occur during the oxides of nitrogen audit, if the monitoring station being audited is equipped with an oxides of nitrogen analyzer. If it is not so equipped, the ozone source should be checked before and after the audit using the Winnebago instrumentation and the procedures described in section A.2.2.1. After verification of the ozone generation rate, develop the conditions for the audit such as

those indicated in Table A.7.

TABLE A.7 SETTINGS TO USE ON BENDIX CALIBRATOR TO PRODUCE VARIOUS OZONE CONCENTRATIONS

Fixed conditions:

| $P_1$ | $P_{1_{cc}}$ | $P_2$ | Orifice |
|---|---|---|---|
| 80% | 4.0 | 49% | 1 |

| Desired Ozone Conc. (ppm)* | cc Air/min used to dilute NO supply | Orifice used to develop desired air flow |
|---|---|---|
| 0.400 | 526 | 1 |
| 0.200 | 1055 | 1, 2 |
| 0.138 | 1530 | 1, 3 |
| 0.100 | 2104 | 1, 2, 3 |
| 0.083 | 2550 | 1, 4 |
| 0.040 | 5320 | 1, 3, 4, 5 |

*Lamp at 440 set point, 500 range

The Bendix ozone lamp may be calibrated for a higher ozone output. This becomes necessary whenever high sample flow rate instruments are to be audited. For example, a Sign-X or a Dasibi uses a minimum of 2500 cc/minute. This demand would only allow the use of the last two concentrations in the above table. An alternate scheme is given below for high ozone outputs. In this case, the lamp is at SET POINT = 500, RANGE = 1000.

TABLE A.8 VALUES FOR OZONE AUDIT AT HIGH LAMP OUTPUT

| Ozone Desired Conc. ppm | Orifice | Dilution Air LPM |
|---|---|---|
| 0.2550 | 1 + 5 | 3.364 |
| 0.2158 | 1 + 2 + 4 | 3.975 |
| 0.1420 | 1 + 4 + 5 | 6.044 |
| 0.110 | 1 + 2 + 3 + 4 + 5 | 7.730 |

After establishing the appropriate Bendix 8861 settings for the analyzer under audit, introduce each point in turn and record the analyzer response.

A.3.4 MRI 1561 NEPHELOMETER AUDIT

A red and black binding post are located on the right hand side of this instrument. Connect a DVM to these terminals. Do not use the meter on the front cover to assess instrument behavior. Next, proceed as follows:

1. Unhook the inlet hose and plug the intake.

2. Move the "air - operate - Freon" switch to the "air" position.

3. Unplug the lower outlet and wait at least fifteen minutes after the machine is turned on or until meter reading and/or voltage output are steady.

4. Readout should be 0.00 VDC $\pm$ .03. Record this voltage.

5. Connect a jumper from TP-1 to TP-8 on the electronic board. Record the voltage after it reaches a steady value. Remove jumper when step 5 is complete.

6. Unhook the tubing coming from the top of the glass "T" above the small clean air pump. Insert the delivery tube from the Freon-12 bottle in the tubing and turn the valve on the top of the bottle on. A flow-limiting orifice is in this valve, supplied by the vendor along with the bottle, so that proper flow occurs when the valve is fully open.

7. After the readout becomes steady, record the voltage.

8. Connect a jumper from TP-1 to TP-9. Readout should rise slowly. When it is steady, record the voltage.

9. Remove the jumper and record the voltage after it again stabilizes.

A.3.5 AUDIT PROCEDURE FOR ATMOSPHERIC METHANE, CARBON MONOXIDE AND TOTAL HYDROCARBONS

Establish a flow of zero air from a tank of known purity as follows: connect a 1/4" Teflon line to the tank and terminate this line with a "T". One side of the "T" goes to the sample air inlet of the instrument under test and the other side goes to a rotameter. The outlet valve on the tanks is regulated so as to keep excess air flowing through the rotameter. If

the demand of the instrument under test exceeds the regulated output of the tank the rotameter reading will fall to zero and the instrument under test will take in ambient air. After a voltage value is established for zero air, replace the zero air tank with a tank containing a gas mixture of known composition and obtain the analyzer response for the mixture.

As an alternate procedure, the audit standards are prepared in Teflon bags. The bags are first purged and evacuated several times with zero air. The bags are then filled with audit gas(es) and delivered for introduction to the analyzer audited. Sampling in this case is directly from the bag to the analyzer through the analyzer sample line with no external venting.

## A.4 AIR MANAGEMENT

Because of the fact that the Bendix calibrator does not produce air of quality adequate for all audits, it is frequently necessary to substitute cylinder zero air. Depending upon whether the audit is performed at a RAMS station using RAMS zero air, or at some other location, the choice of zero air is somewhat determined by the pollutant under study. A comparison of RAMS station zero air (No. 101 on 2/20/76) and Scott cylinder zero air showed the following:

| ANALYZER | STATION AIR Analyzer Response, Volts/ppm | CYLINDER AIR Analyzer Response, Volts/ppm |
|---|---|---|
| $O_3$ | .0284/ .000 | .0207/-.001 |
| NO | -.0056/-.002 | .0402/ .002 |
| $NO_X$ | .0479/-.002 | .0476/-.002 |
| TS Low | .0634/-.002 | .1171/-.001 |
| $H_2S$ Low | .0284/-.002 | .1134/ .000 |
| $SO_2$ Low | .0284/-.002 | .0976/ .000 |
| CO | .1310/-.036 | .1318/-.034 |
| $CH_4$ | .1896/-.017 | .0683/-.267 |
| THC | .2368/-.198 | .2575/-.149 |

In general:

1) The Bendix auditor with charcoal scrubbers will furnish air of sufficient quality to audit only the sulfur, NO, and ozone analyzers.

2) Ultra pure cylinder air should be used for $CH_4$, CO, and THC. The Bendix auditor is not capable of removing these gases from ambient air. RAMS station zero air is generally of high quality but depends on the efficient operation of a catalytic oxidizer.

# APPENDIX B

# MODIFIED BENDIX MODEL 8861 PORTABLE CALIBRATION SYSTEM

CONTENTS


B.1 Introduction 102

B.2 Modifications 103

B.2.1 Zero Air System 103

B.2.2 Flow Measuring System 103

B.2.3 Permeation Tube Chamber 115

B.2.4 Monitoring Console 118

B.3 Instructions for Use of the Modified 8861 123

FIGURES


| Number | | Page |
|---|---|---|
| B.1 | Modified Bendix 8861P Flow Diagram | 104 |
| B.2 | Modified Bendix 8861D Flow Diagram | 105 |
| B.3 | MFM #1 | 108 |
| B.4 | MFM #2 (NO) | 110 |
| B.5 | MFM #3 (Ozone) | 112 |
| B.6 | MFM #4 (Sulfur) | 114 |
| B.7 | Permeation Tube Holder | 116 |
| B.8 | Modified Bendix 8861P Permeation Tube Holder | 117 |
| B.9 | Calibration of Fenwal GB41P2 Thermistor | 119 |
| B.10 | Wiring Diagram | 122 |


TABLES


| Number | | Page |
|---|---|---|
| B.1 | Mass Flow Meter No. 1 (Main Dilution Air) | 107 |
| B.2 | Mass Flow Meter No. 2 (NO) | 109 |
| B.3 | Mass Flow Meter No. 3 (Ozone) | 111 |
| B.4 | Mass Flow Meter No. 4 ($SO_2$) | 113 |
| B.5 | Pin Assignments - Mass Flow Meters | 120 |

## B.1 INTRODUCTION

During the course of RAMS-RAPS audit work involving the routine use of the Bendix Model 8861 portable calibration system, a number of problem areas were noted. Experience gained during the use of the system enabled the audit team to design, install, and test several modifications to the calibrator to improve reliability in future use. The modifications and the instructions for use of the modified 8861 are reported herein.

## B.2 MODIFICATIONS

All modifications to the 8861 are referenced to Figure B.1, the Modified Bendix 8861P Flow Diagram and Figure B.2, the Modified Bendix 8861D Flow Diagram. All modifications have been completed, tested, and documented.

### B.2.1 ZERO AIR SYSTEM

As delivered, the Bendix 8861D dilution air system is supplied with a small and generally inadequate zero air scrubber system. Only at relatively low flow rates and low background pollutant levels was the supplied scrubber found to be adequate. The stock scrubber was removed and replaced with Drierite columns as shown in Figure B.2. Generally a single column containing 6-16 mesh coconut shell activated charcoal was found to be adequate for pollutant removal. Two columns charged with Drierite were used for water vapor removal. Ascarite was employed only in cases where carbon dioxide removal was required and this usage occurred only during the investigation of the effect of carbon dioxide on the response of flame photometric sulfur dioxide analyzers.

The series configuration of Drierite and charcoal was adequate for all audit work conducted with the exception of audits involving carbon monoxide and/or hydrocarbon analyzers. Cylinder zero air was substituted in these instances.

### B.2.2 FLOW MEASURING SYSTEM

Flow control within the Bendix 8861 as delivered is by pressure drop across capillaries. All five dilution air capillaries and the nitric oxide capillary are housed in a thermostated chamber. Purge flow through the permeation tube chamber is controlled by capillary but this capillary is not temperature controlled.

During the course of work involving the 8861, it became obvious that

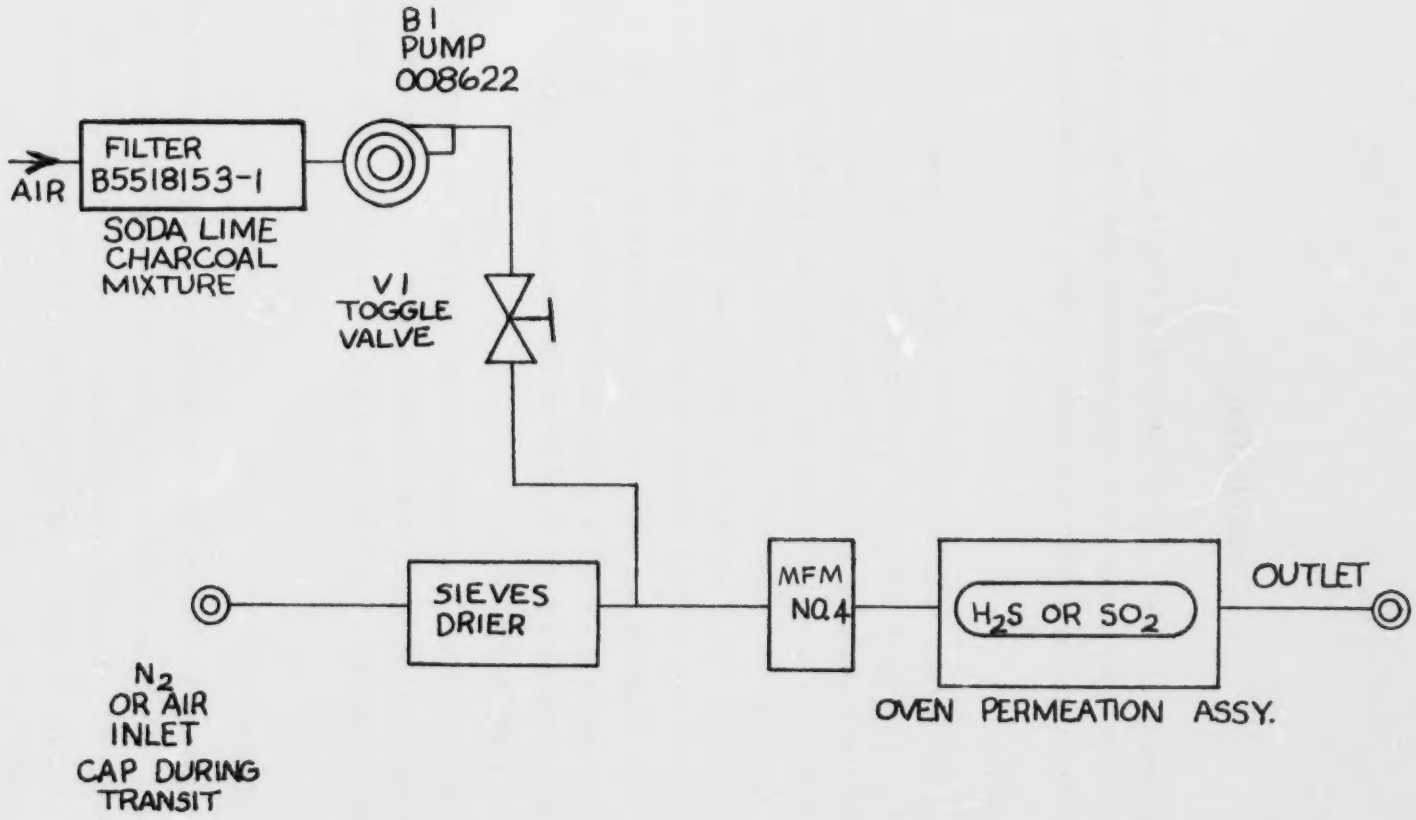



FIGURE B.1 MODIFIED BENDIX 8861P FLOW DIAGRAM

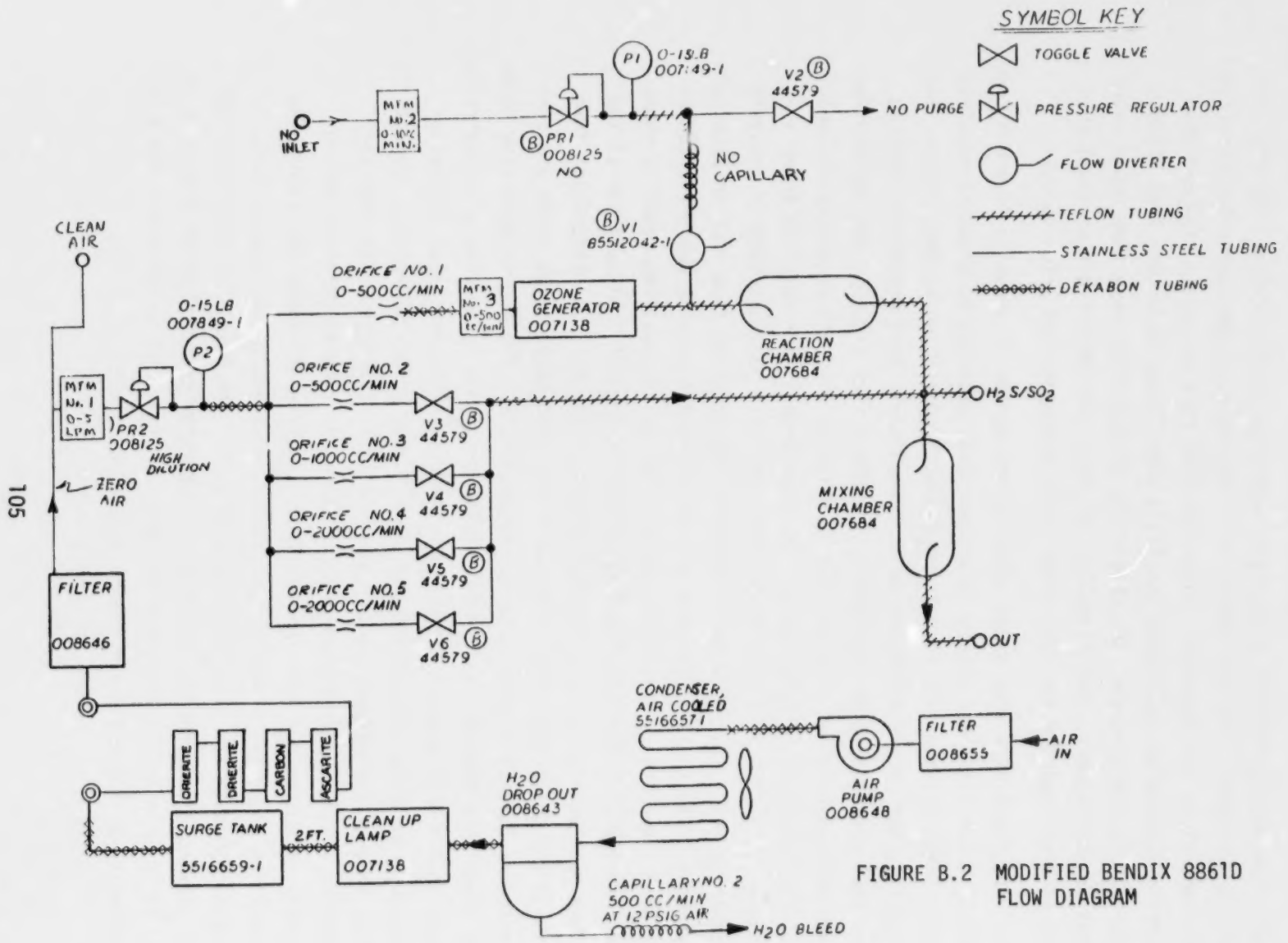



FIGURE B.2 MODIFIED BENDIX 8861D FLOW DIAGRAM

mass flow meters would be a desirable addition to the system. The 8861 is only conveniently flow calibrated in a laboratory under controlled conditions of temperature and pressure. Since the 8861 must be transported and used under a variety of conditions involving significant departure from normal temperature and pressure, the capability of measuring mass flow would represent an improvement. Additionally, the mass flow meters are an invaluable aid in leak checking the 8861 after field transport and prior to use.

The first mass flow meter added to the system is shown in Figure B.2 as MFM 1, a 0-5 liter per minute Tylan unit just upstream of pressure regulator PR2. Total dilution air flow is conveniently monitored at this point. Additionally, the entire 8861D system is conveniently leak checked by sealing the 8861 outlet port and monitoring the MFM 1 flow signal. The calibration data and calibration curve for MFM 1, Dilution Air, are presented as Table B.1 and Figure B.3 respectively. The second mass flow meter is shown in Figure B.2 as MFM 2, a 0-10 cc/minute Tylan unit just upstream of pressure regulator PR1. This flow meter monitors nitric oxide flow from an external cylinder. The calibration data and the calibration curve are presented as Table B.2 and Figure B.4 respectively. The third mass flow meter is shown in Figure B.2 as MFM 3, a 0-500 cc/minute Tylan unit just upstream of the ozone generator serving to monitor the air flow over the ultraviolet lamp within the generator. The calibration data and calibration curve are presented as Table B.3 and Figure B.5 respectively. The fourth mass flow meter is shown in Figure B.1 as MFM 4, a 0-100 cc/minute Tylan mass flow controller just upstream of the permeation tube chamber. This mass flow controller replaces the flow controlling capillary which, prior to removal, limited flow through the permeation tube chamber to 5 cc/minute. The capillary removed was not thermostated and variations in room temperature during audits of sulfur analyzers caused the purge flow to change and eventually result in an analyzer trace in oscillation reflecting the cyclic flow pattern through the permeation tube chamber. The mass flow controller has eliminated this problem and enables an operator selected purge flow rate up to 100 cc/minute. The calibration data and calibration curve for MFM 4 is presented as Table B.4 and Figure B.6 respectively.

TABLE B.1 MASS FLOW METER NO. 1 (Main Dilution Air)

| MFM #1 VOLTS | P-2 % OF GAUGE | TIME FOR 1000CC | OBSERVED FLOW CC/MINUTE | FLOW CC/MINUTE AT ST'D CONDITIONS | ORIFICE |
|---|---|---|---|---|---|
| 0.500 | 47.5 | 118.6 sec | 506 | 451 | 1 |
| 1.000 | 51.0 | 58.0 | 1034 | 922 | 1 + 2 |
| 1.500 | 18.5 | 39.2 | 1531 | 1364 | 1 + 2 + 3 |
| 2.000 | 49.0 | 30.0 | 2000 | 1782 | 1 + 2 + 3 |
| 2.500 | 88.0 | 110.2* | 2517 | 2243 | 1 + 2 + 3 |
| 3.000 | 18.0 | 100.2* | 2994 | 2668 | 1 + 2 + 3 + 4 |
| 3.500 | 32.5 | 86.6* | 3464 | 3087 | 1 + 2 + 3 + 4 |
| 4.000 | 49.0 | 75.6* | 3968 | 3536 | 1 + 2 + 3 + 4 |
| 4.500 | 68.5 | 67.4* | 4451 | 3966 | 1 + 2 + 3 + 4 |
| 5.000 | 90.0 | 60.0* | 5000 | 4456 | 1 + 2 + 3 + 4 |
| 5.500 | 41.0 | 55.0* | 5455 | 4861 | 1 + 2 + 3 + 4 + 5 |
| 6.000 | 54.5 | 50.0* | 6000 | 5347 | 1 + 2 + 3 + 4 + 5 |

*Time for 500 cc

All flows corrected to standard conditions of 0°C and 760 mm Hg.

$$\text{Correction factor} = \text{Observed Flow} \times \left[\frac{273}{273 + 21}\right] \left[\frac{748 - 18.6}{760}\right]$$

$$= 0.891$$

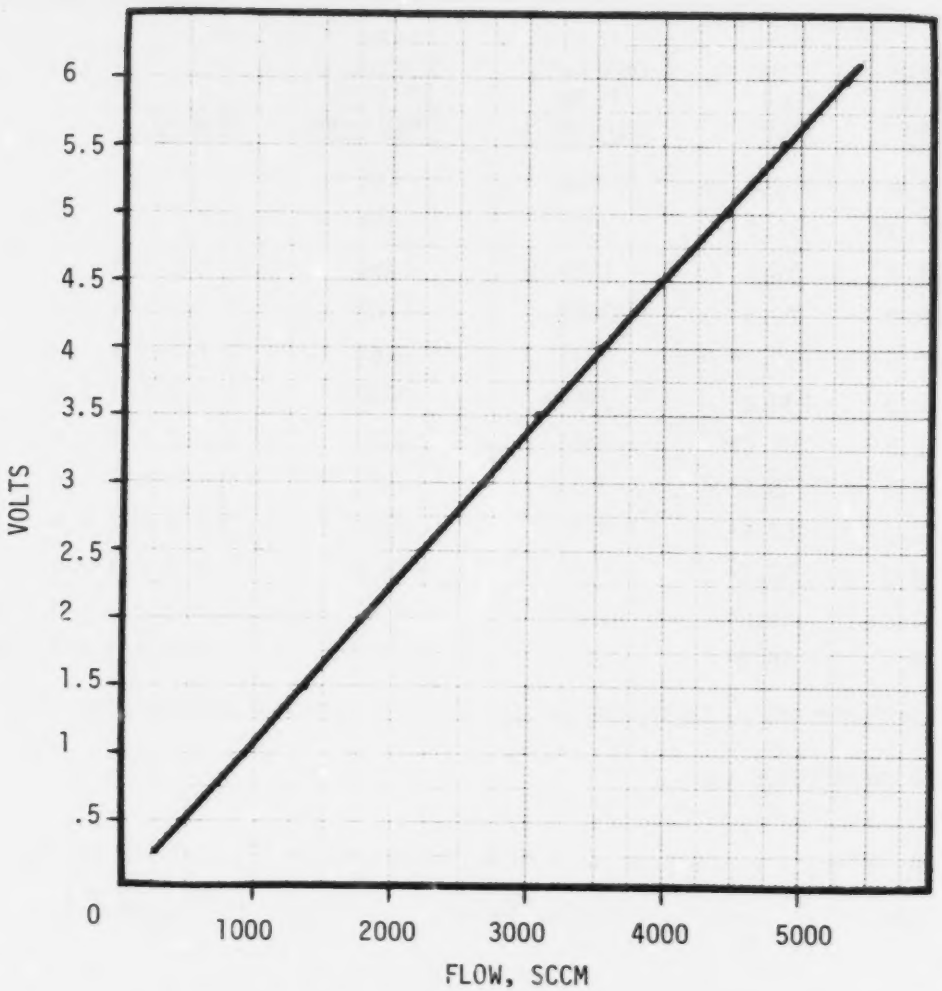



FIGURE B.3 MFM #1

TABLE B.2 MASS FLOW METER NO. 2 (NO)

| MFM #2 VOLTS | P-2 % OF GAUGE | TIME FOR 4.0 CC | OBSERVED FLOW CC/MINUTE | FLOW CC/MINUTE AT ST'D CONDITIONS |
|---|---|---|---|---|
| 0.445 | 10 | 217.0 | 1.106 | 0.99 |
| 0.618 | 20 | 158.2 | 1.517 | 1.36 |
| 0.800 | 30 | 124.9 | 1.922 | 1.72 |
| 1.000 | 46 | 101.8 | 2.358 | 2.11 |
| 1.220 | 50 | 83.8 | 2.864 | 2.56 |
| 1.446 | 60 | 69.0 | 3.478 | 3.11 |
| 1.670 | 70 | 60.3 | 3.980 | 3.56 |
| 1.920 | 80 | 53.0 | 4.528 | 4.05 |
| 2.175 | 90 | 47.2 | 5.085 | 3.55 |
| 2.452 | 100 | 41.4 | 5.797 | 5.19 |

All flows corrected to standard conditions of 0°C and 760 mm Hg.

$$\text{Correction factor} = \text{Observed Flow} \times \left[\frac{273}{273 + 23.8}\right]\left[\frac{759.2 - 22.1}{760}\right]$$

$$= 0.892$$

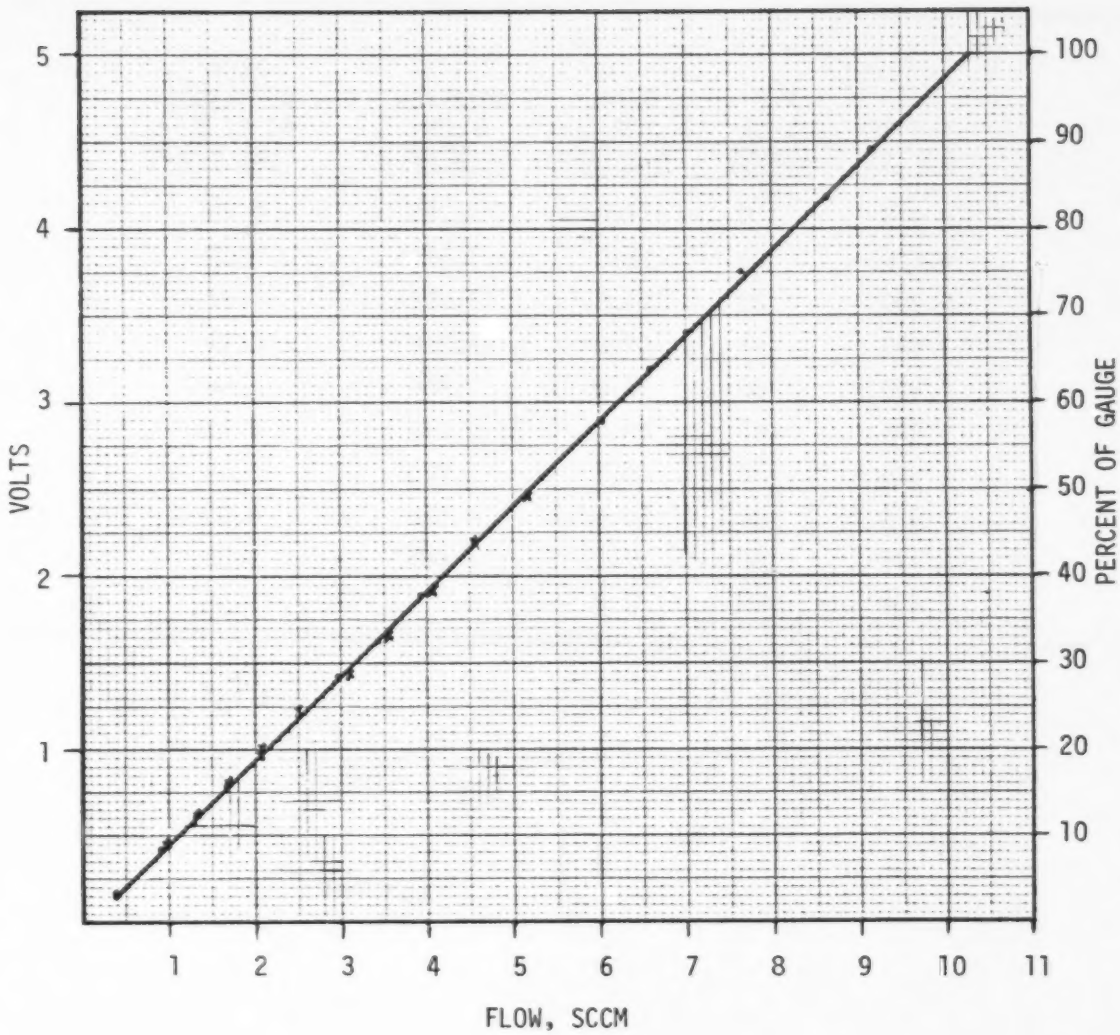



FIGURE B.4 MFM #2 (NO)

TABLE B.3 MASS FLOW METER NO. 3 (Ozone)

| MFM #3 VOLTS | P-2 % OF GAUGE | TIME FOR 1000 CC | OBSERVED FLOW CC/MINUTE | FLOW CC/MINUTE AT ST'D CONDITIONS |
|---|---|---|---|---|
| 3.151 | 10 | 172.4 | 348 | 310 |
| 3.598 | 20 | 150.8 | 398 | 355 |
| 3.975 | 30 | 136.8 | 438 | 390 |
| 4.341 | 40 | 125.4 | 478 | 426 |
| 4.705 | 50 | 115.8 | 518 | 462 |
| 5.020 | 60 | 108.8 | 551 | 491 |
| 5.317 | 70 | 101.8 | 589 | 525 |
| 5.616 | 80 | 96.8 | 620 | 553 |
| 5.889 | 90 | 91.4 | 656 | 585 |
| over range | 100 | 87.4 | 686 | 611 |

All flows corrected to standard conditions of 0°C and 760 mm Hg.

$$\text{Correction factor} = \text{Observed Flow} \times \left[\frac{273}{273 + 21}\right] \left[\frac{748 - 18.65}{760}\right]$$

$$= 0.891$$

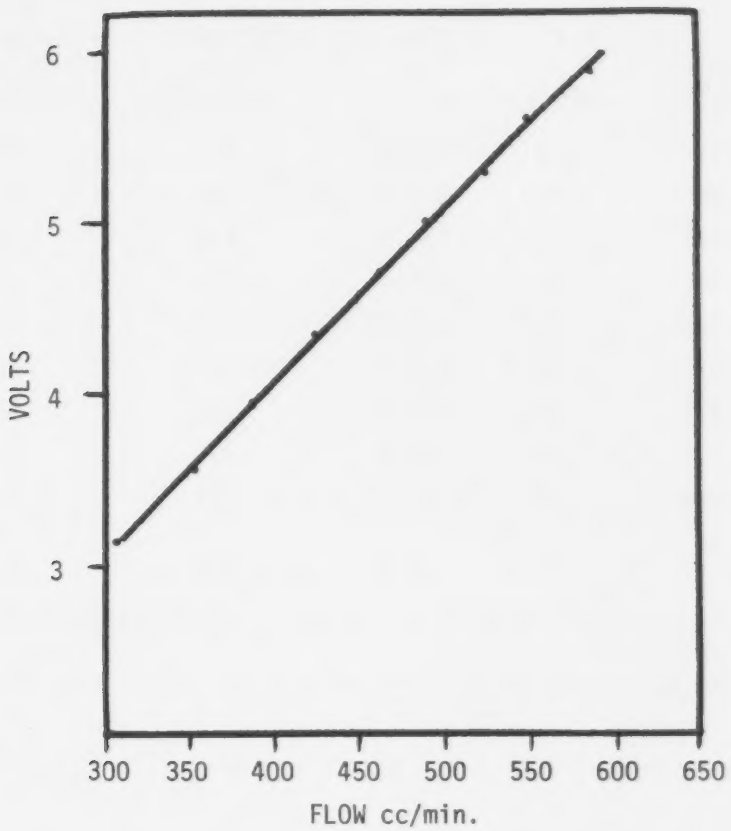



FIGURE B.5 MFM #3 (Ozone)

TABLE B.4 MASS FLOW METER NO. 4 ($SO_2$)

This is a mass flow controller operating from a 10 turn command potentimeter.

| POTENTIMETER READING | MFM #4 VOLTS | TIME FOR 10 CC | OBSERVED FLOW CC/MINUTE | FLOW CC/MINUTE AT ST'D CONDITIONS | OVEN TEMPERATURE (VOLTS) |
|---|---|---|---|---|---|
| 100 | 0.486 | 53.9 | 11.131 | 9.939 | 0.548** |
| 200 | 0.975 | 26.6 | 22.556 | 20.141 | 0.548** |
| 300 | 1.467 | 17.8 | 33.708 | 30.099 | 0.548** |
| 400 | 1.956 | 13.3 | 45.113 | 40.283 | 0.548** |
| 500 | 2.445 | 10.6 | 56.604 | 50.543 | 0.548** |
| 600 | 2.938 | 89.8* | 66.815 | 59.661 | 0.548** |
| 700 | 3.426 | 78.2* | 76.726 | 68.511 | 0.548** |
| 800 | 3.918 | 68.2* | 87.976 | 78.556 | 0.548** |
| 900 | 4.410 | 60.7* | 98.847 | 88.263 | 0.548** |
| 1000 | 4.905 | 54.6* | 109.890 | 98.124 | 0.548** |

* Time for 100 cc

** 0.548 volts corresponds to 30.00°C

All flows corrected to standard conditions of 0°C and 760 mm Hg.

. Correction factor = Observed Flow x $\left[\frac{273}{273 + 22}\right]\left[\frac{753.1 - 19.8}{760}\right]$

= 0.893

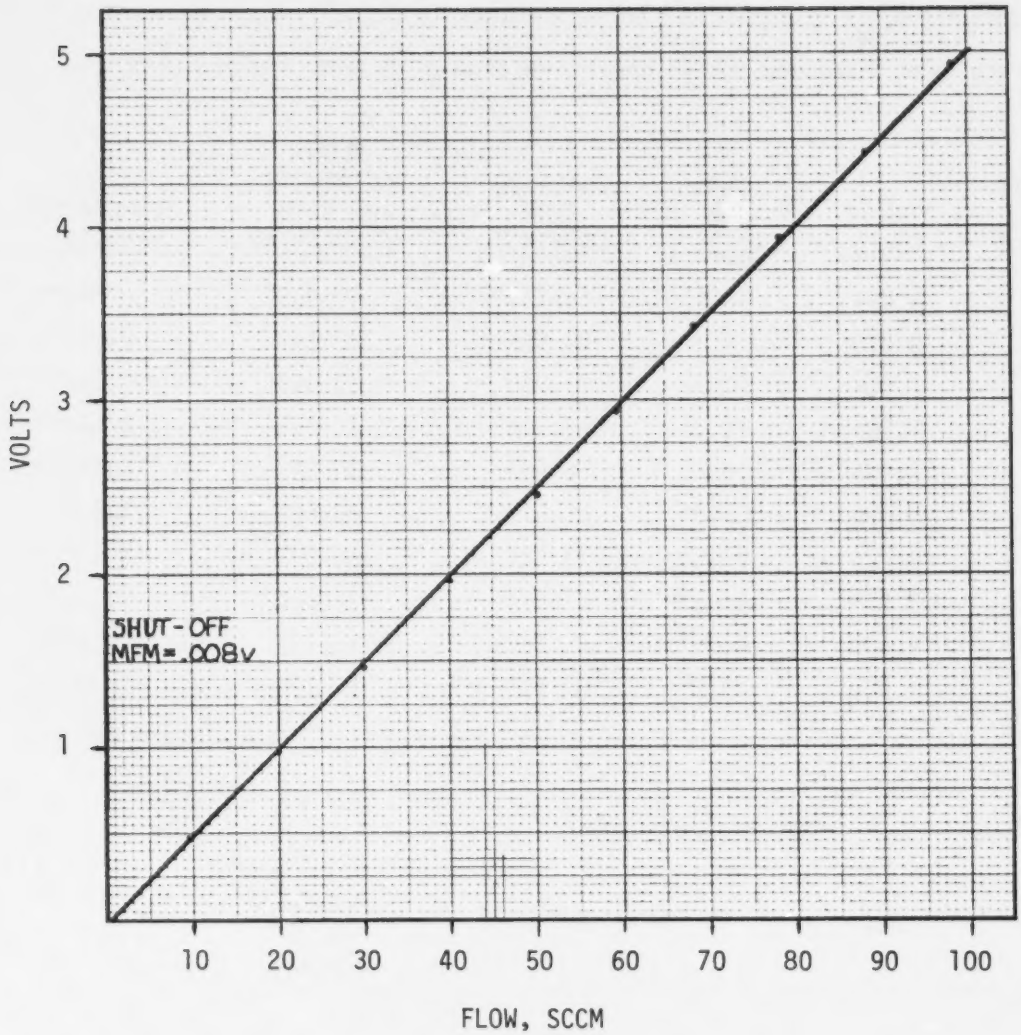



FIGURE B.6 MFM #4 (Sulfur)

B.2.3 PERMEATION TUBE CHAMBER

A platinum resistance thermometer which measures the temperature of the permeation tube is part of the Bendix design. It does not measure the air temperature surrounding the permeation tube but rather the temperature of a massive aluminum block surrounding the inner chamber.

A redundant back-up system capable of measuring purge air temperature seemed highly desirable and was installed. A 3/4" diameter Teflon rod was bored out, milled and threaded as shown in Figure B.7. The interior was enlarged to accommodate two 5.0 cm permeation tubes. As a precaution against future leaks, stainless steel bands were turned on the lathe and press-fit over the ends of the Teflon permeation tube holder. As Teflon ages it has a tendency to spread, which could cause leaks at both ends of the holder. The steel bands will prevent this from occurring.

A male run "T" was fitted to the rear of the holder and a previously calibrated glass thermistor was sealed into the side of the "T". The thermistor was secured in place and the joint was made gas tight using epoxy cement. Finally, a five foot length of 1/8" copper tubing was spirally wound around the Teflon permeation tube holder and the three components were assembled as shown in Figure B.8. The entire assembly is contained within the permeation tube oven.

The outlet of the permeation tube holder was plugged, 15 psi air was introduced and the system was leak-tested. The new design advantage becomes obvious at this point. If the rear connections are leak-free it is unlikely they will leak in the future because this connection is never disturbed. (In the old design, the permeation tube was inserted from the rear.) To reconnect the permeation tube holder to the purge air it is only necessary to make a final connection between the 'air in' and the outlet of mass flow controller No. 4. This connection is accessible for leak checking.

To change permeation tubes the front fitting (purge air exit) can be removed and the permeation tube becomes accessible with forceps. The entire assembly is free to slide from the oven. Tilting the assembly discharges the permeation tube from the Teflon cavity. After a new tube

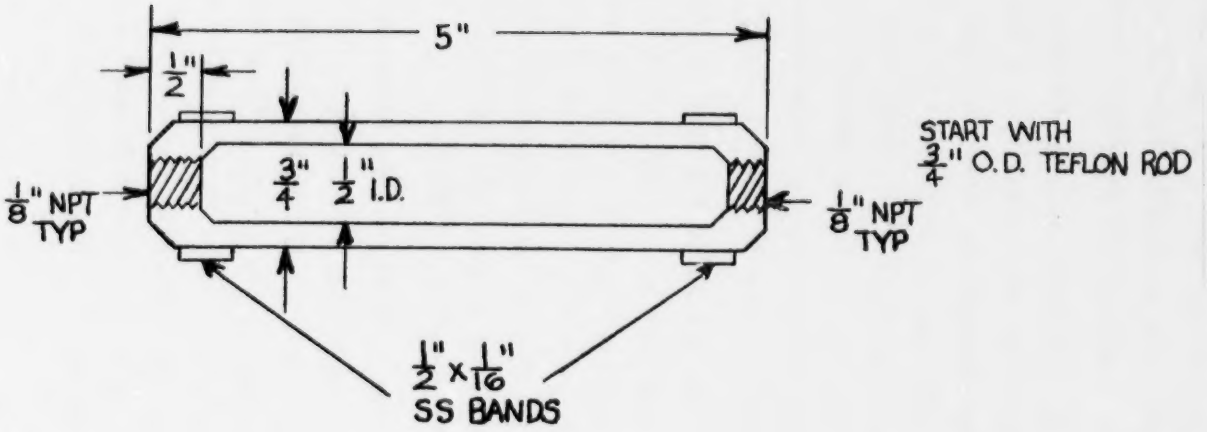



FIGURE B.7 PERMEATION TUBE HOLDER

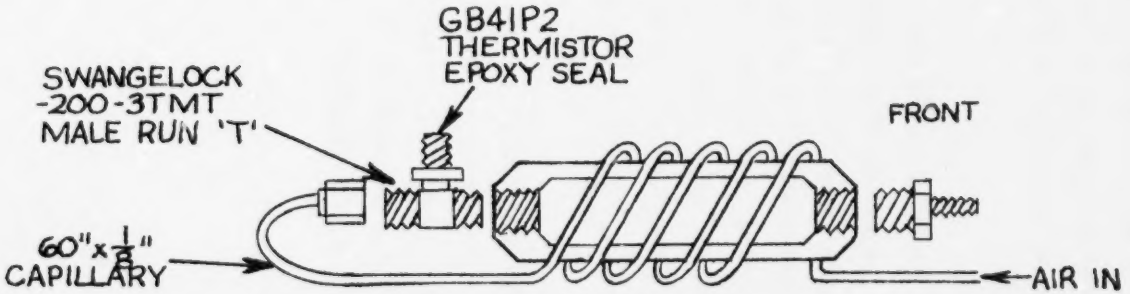



FIGURE B.8 MODIFIED BENDIX 8861P PERMEATION TUBE HOLDER

is inserted, all leak checks can be made external to the chamber.

With the new design, the purge air temperature may be monitored directly just prior to exposure to the permeation tube. The leading copper tubing insures that air temperature reaches the control temperature of 30.0°C regardless of ambient temperature. The data included in Table B.4 clearly shows that this temperature is maintained throughout the 0-100 SCCM operating range of MFC 4. The calibration curve for the Fenwal thermistor installed in the tube holder is presented as Figure B.9.

### B.2.4 MONITORING CONSOLE

The wiring diagram for the monitoring console enabling an operator to display any mass flow meter signal or thermistor signal is shown in Figure B.10. All pin assignments are given in Table B.5. The console consists of a 6000 count digital voltmeter mounted in a control panel. The input to the DVM is switched to display either the thermistor signal (position 1) or the mass flowmeter signals (MFM 1-4, positions 2-5). The command potentiometer for MFM 4 is also mounted on the panel. The pot is 10-turn and is linearly proportional to a flow of 0-100 cc/minute through the permeation tube chamber.

All of the mass flow meters require a regulated $\pm$ 15 VDC supply for operation. Connections to Tylan power supply PS-14 are shown in Figure B.10. Detail for connections (typical, 4 places) to MFM 4 is also shown in Figure B.10. The Fenwal thermistor mounted in the permeation tube chamber is in a voltage divider across the regulated + 15 VDC Tylan supply.

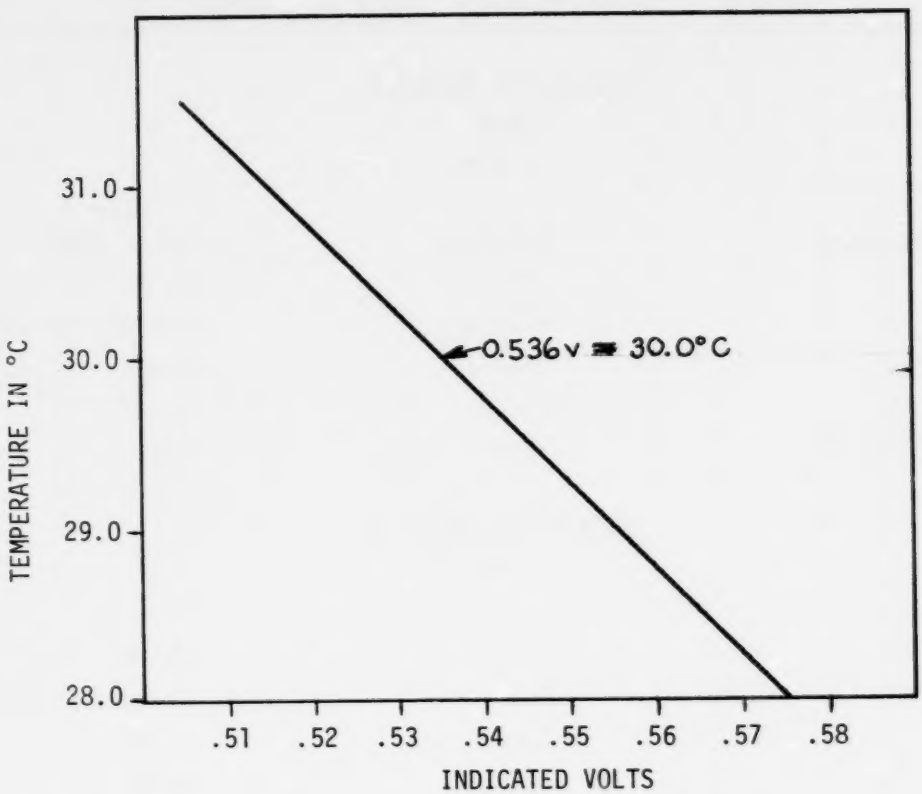



FIGURE B.9 CALIBRATION OF FENWAL GB41P2 THERMISTOR

TABLE B.5 PIN ASSIGNMENTS - MASS FLOW METERS

| Pin Assignment | Function | Wire Color Code |
|---|---|---|
| | FLOW METER NUMBER 1 | |
| | AIR | |
| | 0-5LPM | |
| W | -15 V | White |
| S | Case Gnd. | Braided shield |
| 17 | Common | Black |
| U | Output | Green |
| V | +15V | Red |
| | FLOW METER NUMBER 2 | |
| | NO | |
| | 0-10 cc/min | |
| R | -15V | White |
| L | Case Gnd. | Braided shield |
| 12 | Common | Black |
| N | Output | Green |
| P | +15V | Red |
| | FLOW METER NUMBER 3 | |
| | OZONE | |
| | 0-55 cc/min | |
| K | -15V | White |
| E | Case Gnd. | Braided shield |
| 7 | Common | Black |
| F | Output | Green |
| J | +15V | Red |

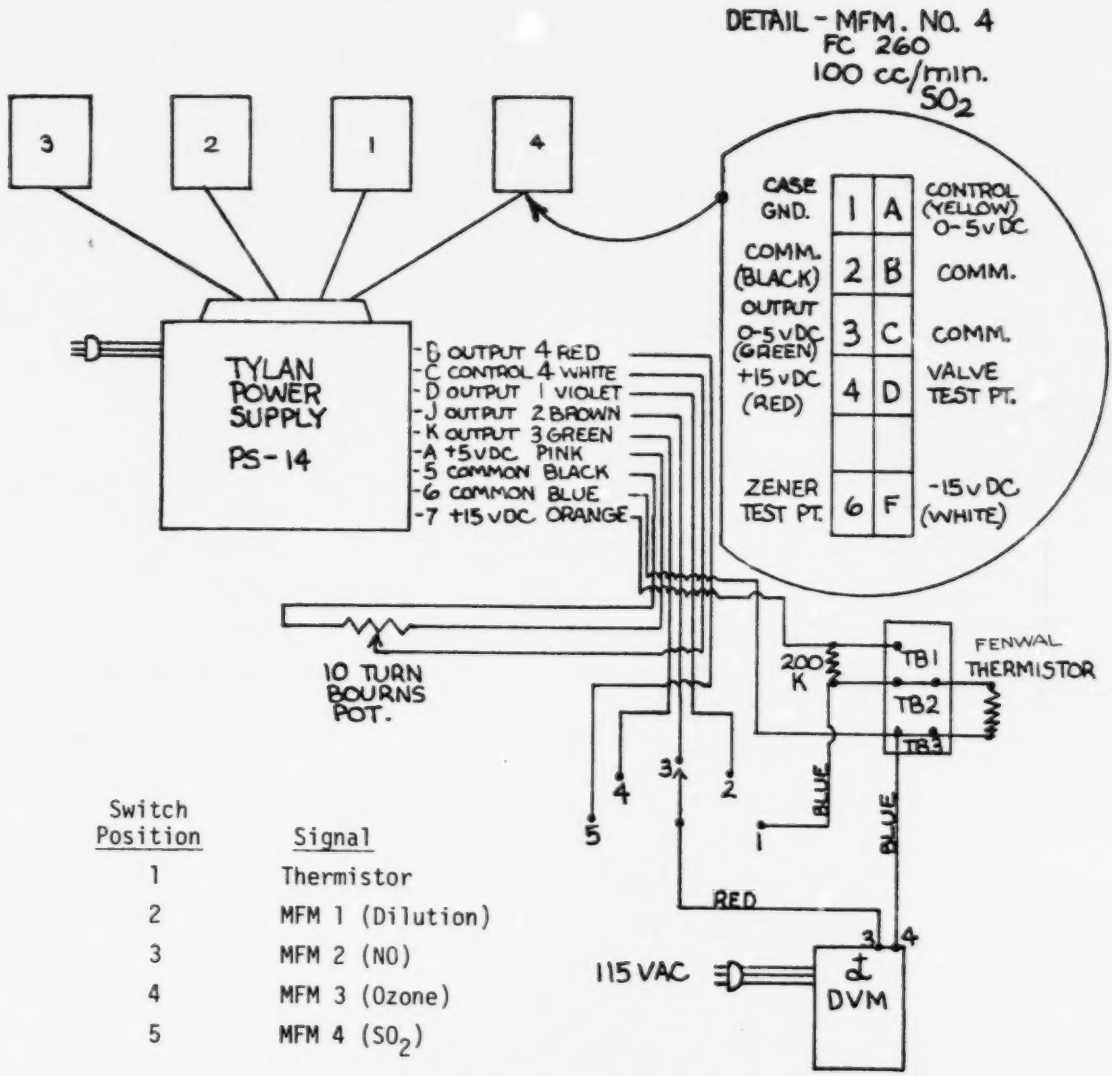
(continued)

TABLE B.5 (continued)

FLOW METER/CONTROLLER NUMBER 4

$SO_2$
0-100 cc/min

| Pin Assignment | Function | Wire Color Code |
|---|---|---|
| 25 | -15V | White |
| Y | Central | Yellow |
| X | Case Gnd. | Braided Shield |
| $\overline{a}$ | Common | Black |
| Z | Output | Green |
| $\overline{b}$ | +15V | Red |




| Switch Position | Signal |
|---|---|
| 1 | Thermistor |
| 2 | MFM 1 (Dilution) |
| 3 | MFM 2 (NO) |
| 4 | MFM 3 (Ozone) |
| 5 | MFM 4 ($SO_2$) |

FIGURE B.10 WIRING DIAGRAM

(Interconnections between Power Supply - Mass Flow Meter and Control Box mounted on the modified Bendix 8861P)

## B.3 INSTRUCTIONS FOR USE OF THE MODIFIED 8861

The following operating procedures pertain to the operation of the modified Bendix 8861D and 8861P and involve the use of mass flow meters to measure the flow of dilution air and/or calibration gas delivered by the above.

To set up for audit proceed as follows:

1. Open both cases, side by side and make the following interconnections;

   a) Connect the 52" Teflon line between the "Clean Air" on the 8861D and the input filter marked "air in" in the 8861P. This line supplies purge air to the $SO_2$ permeation assembly. Refer to Figure B.1, Modified Bendix 8861P Flow Diagram and Figure B.2, Modified Bendix 8861D Flow Diagram.

   b) Turn the toggle switch V1, Figure B.1 to "off" when the pump in the 8861D is started.

   c) Make sure the air scrubbers are connected together as shown in Figure B.2 (i.e., drierite - drierite - carbon - ascarite). Connect the first drierite bulb to the air "out" and the outlet of the ascarite bulb to the "in" connections on the 8861D. These scrubbers will produce dry pollutant free air, free of carbon dioxide. Under certain conditions it may be advisable to use charcoal alone depending on the analyzer being calibrated or audited.

   d) Connect the mass flow meter cables being careful to match the number on the plug with the number on the mass flow meter (i.e., No. 1, 5.0 LPM dilution air; No. 2, 10 cc NO; No. 3, 500 cc ozone; No. 4 100 cc $SO_2$). Use the Phillips head screws to secure the plug to the circuit board connection on the top

of the mass flow meter.

e) Plug in the 8861D using the plug strip mounted in the 8861P and connect the plug strip to a 115V source.

f) Turn on the power switch on the 8861D. This turns on the pump. The toggle valve mentioned in part b) above can now be turned to "off" and the "stand-by - off-on" switch on the 8861P can now be turned to "on".

The equipment is now in operation.

2. Dilution flow calculations can be made as shown in the "Audit Procedures for RAPS Instrument Systems" and reviewed briefly below:

For $SO_2$:

$$C = \frac{PR \times K}{F_p + F_d}$$

where: C is concentration in PPM
PR is permeation rate in ng/min. (Ref. oven temperature)
K is 22.4/M.W. of permeation gas (M.W. $SO_2$ = 64)
$F_p$ is permeation oven flow rate
$F_d$ is dilution flow rate

For NO:

$$C_1V_1 = C_2V_2$$

where: $C_1$ is concentration of NO source gas
$V_1$ is the flow rate of NO source gas
$C_2$ is final concentration
$V_2$ is total dilution flow rate.

3. The quantity of dilution flow can be read from the graphs accompanying this report. The total dilution air flow is read from mass flow meter No. 1, the NO flow is read from mass flow meter No. 2, the ozone is read from mass flow meter No. 3 and the $SO_2$ is read from mass flow meter No. 4. The volume of purge air entering the permeation oven is continuously variable between 2-100 cc/min and care must be taken to insure that this volume is added to $F_d$ when

the flow calculations are made.

4. On shut-down, disassemble in the reverse order to set-up and observe the following precautions:

   a) Turn the "stand-by, off, on" switch to stand-by. The air pump is now running off the internal battery in the 8861P.

   b) The toggle valve V1 is turned to "on".

   c) The "air-in" filter in the 8861D is closed with a cap. If this is not done, air from the pump escapes through the filter and no purge air goes through the permeation oven. As a final check, turn the selector switch on the control panel to position 5 and note that a voltage is indicated on mass flow meter No. 4 showing that purge air is flowing through the permeation oven.

   d) The Bendix 8861P should not be left on its stand-by battery for more than 24 hours. High current drain will nearly totally discharge the battery in this time interval.